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Alternative Methods for Disposal of Low-Level Radioactive Wastes

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Task 2b: Technical Requirements for Aboveground Vault Disposal of Low-Level Radioactive Waste

Prepared by R. D. Bennett, J. B. Warriner

Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

Current practice in the US for disposal of commercial low-level radioactive wastes (LLW) is burial in shallow trenches. In 1983, approximately 110,000 cubic meters of these wastes were disposed of at the three operating commercial sites. Three additional sites have ceased operations in the past decade and are awaiting technical and institutional determinations that will allow for final closure. Although shallow land burial in trenches may continue to be practiced, it is likely that techniques for engineered disposal will be introduced to the NRC or states for licensing consideration within the next few years.

Aboveground vault disposal is one of several methods that may be proposed. In this report, the term "aboveground vault" refers to an engineered structure with roof, walls, and floor enclosing the disposal space. The floor may be man-made materials or natural or treated soil or rock. Wastes may be emplaced through openings in the roof or through doors in the walls. The vault is assumed to be partially or completely exposed to the atmosphere. The limited experience and knowledge gained with this method are described and updated in this report. This short-term experience does not conclusively demonstrate the capability of the aboveground vault disposal method to satisfy the performance objectives specified by the NRC in 10 CFR Part 61 Subpart C.

The lack of experience, together with the inherent difficulties of satisfying some of the performance objectives discussed herein, such as the avoidance of the need for long-term active maintenance, raises serious questions about the ability of aboveground vault disposal to meet the performance objectives and related technical requirements.

A generic description of the features and components and operation of an aboveground vault disposal facility is provided. Features and components that could enhance the long-term performance are also described.

The existing criteria developed for near-surface disposal (10 CFR Part 61 Subpart D) were assessed for applicability to the disposal method in Task 1 of this study and were reassessed in Task 2, as reported herein. With few exceptions, these criteria were found to be applicable in the reassessment. However, satisfaction of several of the technical requirements may be difficult in practice. The conclusions of the criteria assessment differ slightly from the Task 1 findings in which modification of six existing criteria were recommended. These differences are explained in the text.

Additional technical considerations that should be addressed are recommended. These considerations include:

a. The need for assessment of the occurrence and potential adverse impacts from dispersive soils, corrosive soils, solution cavities,

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liquefiable soils, expansive soils, and areas undergoing land subsidence.

b. The need to plan for individual disposal unit closure.

c. The need to consider requirement of features that could enhance the long-term performance of the facility.

d. The need for submittal of a detailed plan for remedial actions should they become necessary. This plan should identify specific events that would trigger specific actions and the reaction times involved.

Finally, research is recommended for unresolved questions about the long-term durability and performance of materials used in engineered facilities. Appendix A, which describes factors that impair the long-term durability of concrete and design and construction methods that can be used to minimize the adverse impacts, is a step in this direction.

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COL Tilford C. Creel and COL Robert C. Lee, were Commanders and Directors of WES during most this study, and COL Allen F. Grum was Director of WES during the final part of the study. Mr. Fred Brown and Dr. Robert W. Whalin were Technical Directors.

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1. INTRODUCTION

1.1 Background

The Atomic Energy Act of 1954 and the Energy Reorganization Act of 1974 gave the US Nuclear Regulatory Commission (NRC) the responsibility for assuring and maintaining public health and safety, as may be affected by all commercial nuclear facilities, including facilities for the disposal of low-level radioactive waste (LLW).

The National Low-Level Radioactive Waste Policy Act of 1980 (Public Law 96-573) gave the individual states responsibility for the management and safe disposal of all commercial LLW generated within their borders. The act allows, subject to congressional approval, that each state may enter into regional compacts with neighboring states to establish and operate regional disposal sites.

The NRC has established uniform procedures for licensing and regulating the disposal of LLW. The procedures are set forth in the Code of Federal Regulations 10 CFR Part 61. Subpart D of 10 CFR Part 61 and related regulatory guidance provide specific technical criteria for land disposal. Specific sections of Subpart D provide technical criteria related to siting, design, operation, and closure of a near-surface disposal facility. Subsections were reserved for methods other than near-surface disposal.

Current practice in the United States is to dispose of commercial LLW by burial in shallow trenches. In 1983 approximately 110,000 cubic meters of these wastes were disposed of at three commercially operated disposal facilities. Waste disposal at three additional sites has ceased in the past decade and these sites are awaiting permanent closure.

Although shallow land burial in trenches may continue to be practiced, it is likely that other techniques for engineered disposal may be submitted to the NRC or the states for licensing consideration within the next few years. It is important that the NRC have uniform criteria or guidance by which engineered facilities may be evaluated and that such criteria or guidance be compatible with the performance objectives set forth in 10 CFR Part 61 Subpart C.

1.2 Purpose and Scope

The overall purpose of this study was to ensure that the technical criteria or guidance required to completely evaluate five alternative methods of LLW disposal were available. The methods to be considered were aboveground vaults, belowground vaults, earth-mounded concrete bunkers, mined cavities, and shafts. Criteria or guidance related to site suitability, design, operations, closure, and monitoring, as listed in 10 CFR Part 61, paragraphs 61.50 through 61.53, were to be assessed. Where judged to be appropriate, recommendations were to be made to modify existing criteria and to address additional technical issues.

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Guidance related to the implementation of criteria for acceptable waste forms and classes that would be appropriate for disposal in specific engineered facilities are also important areas of consideration. However, development of guidance for acceptable waste forms or waste classifications was beyond the scope of this study.

Development of conceptual designs was also not within the scope of this study. However, important features of the various alternatives were illustrated and discussed as they pertain to the satisfaction of the performance objectives. Although segregation of wastes prior to disposal in engineered facilities may be desirable for economic or political reasons, segregation has not been assumed as a requirement for this study.

Cost estimates were not prepared or reported for any of these alternative methods. It is recognized that guidance on conceptual designs and acceptable waste forms and classes appropriate for disposal using these alternatives would be useful to the states or individuals considering them, and that detailed costs would be an important consideration in their adoption. However, the most important issues are whether these methods can meet the performance objectives of Subpart C and how their performance can be judged.

The study was divided into three main tasks. Previous work was described in the Task 1 report (Bennett and others, 1984), and included descriptions of all five alternatives, summaries of the experience with each method, and an initial assessment of the applicability of existing technical criteria relating to site suitability, design, operations, closure, and monitoring.

This report, one of a series, contains the results of subtask 2a of the investigation. Separate reports were prepared for each method investigated. The reports pertaining to the aboveground vault, belowground vault, earth-mounded concrete bunkers, and shaft disposal methods were each issued as one of a series of four. Although each of these methods has some contrasts with shallow land burial, they are accurately considered near-surface disposal methods. The aboveground vault method does not fit the strict definition of disposal <u>within</u> 30 meters of the surface, but is has many characteristics that make it amenable to evaluation using existing criteria.

The mined-cavity disposal alternative is quite different from near-surface disposal. Consequently, during the course of the study, the NRC decided to deal with this method separately from the others.

1.3 Organization

Each of the Task 2 reports has been organized in parallel format as described below.

Each report shares a common introductory section. In Part 2, the performance objectives are listed, the experience with the disposal alternative is summarized and updated, the unit operations and features and components of the

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particular alternative disposal facility are described, and the performance capabilities are summarized. Because of the importance of design features of aboveground vaults in meeting the performance objectives, design considerations for the major features and components are discussed in Part 2.

The technical criteria recommendations are developed in Part 3. The criteria are reassessed one by one, drawing from the assessment and conclusions made in the Task 1 report. The organizational scheme used is to list each criterion as it appears in 10 CFR Part 61, and discuss its objective and relevance to aboveground vault disposal. Next a recommendation is made to:

a. Retain the criterion as is,

b. Not apply the criterion in the evaluation of the particular alternative, or

c. Modify the criterion to make it applicable to the particular alternative.

Any departures or changes from the position taken in the Task 1 report are noted and explained. This procedure is followed for each criterion. At the end of each criteria section, i.e., site suitability, design, etc., suggested additional technical considerations that should be addressed are discussed. These considerations (which are implied within 10 CFR 61.12) may form the basis for additional criteria, if judged to be necessary by the NRC. Specific supplemental criteria are not given in prescriptive language. Rather, the issues that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the NRC to consider those issues and develop specific wording that it considers appropriate on a point-by-point basis. Alternatively, the NRC may wish to provide guidance without changes or additions to existing criteria.

In Part 4, conclusions and recommendations are offered on the feasibility of the disposal concept, the assessment of existing criteria and supplemental considerations, and unresolved issues and research required to resolve them.

All references are listed after the body of the report. A glossary of major terms follows the references.

Because concrete is likely to play an important role in design features of vault disposal facilities, factors that impair long-term durability of concrete and design and construction practices that can be used to minimize adverse impacts are discussed in Appendix A.

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2. THE ABOVEGROUND VAULT DISPOSAL ALTERNATIVE

In the following paragraphs, the aboveground vault alternative is described, including unit operations and design considerations for major components or features of the method, the limited experience gained with its use is summarized from the Task 1 report, and performance capabilities are discussed. Features or components that could enhance the method's performance are also discussed.

The discussion at the end of this section of performance capabilities of the disposal alternative is directed toward satisfaction of the performance objectives and the minimum technical requirements.

It should be noted that for any method to be considered by the NRC for licensing for disposal of low-level radioactive wastes, it must be capable of satisfying the performance objectives of 10 CFR Part 61 Subpart C (paragraphs 61.40 through 61.44). These performance objectives are quoted below.

2.1 Performance Objectives

Paragraph 61.40 - "General requirement. Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in paragraphs 61.41 through 61.44."

Paragraph 61.41 - "Protection of the general population from releases of radioactivity. Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable."

Paragraph 61.42 - "Protection of individuals from inadvertent intrusion. Design, operation, and closure of the land disposal facility must ensure protection of any individual inadvertently intruding into the disposal site and occupying the site or contacting the waste at any time after active institutional controls over the disposal site are removed."

Paragraph 61.43 - "Protection of individuals during operations. Operations at the land disposal facility must be conducted in compliance with the standards for radiation protection set out in Part 20 of this chapter (10 CFR Part 20), except for releases of radioactivity in effluents from the land disposal facility, which shall be governed by Paragraph 61.41 of this part. Every reasonable effort shall be made to maintain radiation exposures as low as is reasonably achievable."

Paragraph 61.44 - "Stability of the disposal site after closure. The disposal facility must be sited, designed, used, operated, and closed to achieve long-

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term stability of the disposal site and to eliminate to the extent practicable the need for ongoing active maintenance of the disposal site following closure so that only surveillance, monitoring, or minor custodial care are required."

2.2 Experience with the Method

Although aboveground vault disposal of LLW has been proposed by various groups in the US, there is not much experience with the method other than short-term storage.

Aboveground vaults are used in Canada for storage of LLW. The New Brunswick Electric Power Commission has built storage vaults on bedrock at its Pt. Lepreau site completely aboveground. An aboveground storage facility is also being used at Ontario Hydro's Bruce site (Charlesworth and Carter, 1982 and Feraday, 1982).

A wide variety of aboveground vaults has been built and successfully used for warehousing manufactured goods, raw materials, and meat and produce. Their wide acceptance shows that they are economical and versatile structures. However, it should be pointed out that these facilities were not designed and constructed for long-term performance as required of LLW disposal facilities.

2.3 Operations, Design Considerations, and Features of an Aboveground Vault Disposal Facility

A disposal facility for LLW that uses aboveground vaults as the disposal units could have a layout and plan of operations similar in some respects to existing shallow land burial facilities. Some operations, design considerations, and features would be unique requirements for this method. Similarly, some operations and features may be considered absolute requirements, while others may be desirable but not essential under all conditions.

2.3.1 Unit Operations

The primary unit operations required at an aboveground vault disposal facility are listed below:

a. Trucks loaded with wastes will be checked in at the entrance, the cargo and manifest checked, and appropriate instructions given to the driver.

b. The truck will proceed to the secure operations area, i.e., the actual disposal area or to a temporary storage area, from which the waste packages will be transferred for disposal later.

c. The waste packages will be unloaded using a mobile crane and placed in the disposal units, using a mobile crane or forklift, depending on configuration of the vault access doors. Control of human occupation time within the vault interiors is recommended, commensurate with waste activity levels and shielding and venting provisions.

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d. After being unloaded, trucks will be surveyed for contamination and decontaminated if necessary before leaving the site.

e. Vaults may be temporarily closed after each shipment is placed. Temporary closure should prevent rainwater or runoff from entering the vault.

f. As the vaults reach capacity, they should be closed. If the vault design includes vents and drains, then closure procedures must account for these openings. Waste emplacement access openings must also be closed.

g. Sampling and monitoring stations, including surface and subsurface points must be established and maintained.

h. Laboratory tests and analyses will be required periodically to verify satisfactory performance and establish a data-base from which trends and anomalies may be discerned.

i. Personnel training and public-relations work will be required.

j. Clearing and grading of new disposal areas and establishment and maintenance of runoff-control features will be required.

k. Additional disposal units must be constructed included necessary appurtenances.

l. Other activities will include surveying, record-keeping for waste receipts, disposal locations, quality-control test results, sampling and monitoring data, and permits and licenses.

2.3.2 Features and Components and Design Considerations

The primary features and components of an aboveground vault disposal facility are listed below:

a. The actual disposal site includes the land for disposal, other operations, and administration. It may be desirable to utilize disposal sites that have sufficient relief to allow gravity drainage of water from the subfloor bed of aggregate to surface or near-surface catchment structures for sampling and disposal. As a corollary, the disposal units should not be located in the lower elevation portions of a site. Placing the units on the higher elevations not only facilitates gravity drainage but also precludes ponding of surface water in their vicinity. Drainage systems must be entirely above the water table in all cases.

b. Security fences, guard shacks, and truck check-in station are required for control of access and egress.

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c. An operations building is required, from which all disposal operations would be initiated.

d. An administration building is required and should include facilities for office work, records storage and retrieval, including personnel records, visitor waiting-room facilities, convenience facilities, and storage areas. Ample parking areas should be provided. The administration building should be outside the secure operations area to minimize the number of employees and visitors that must be checked in and out.

e. Access roads are needed for transportation of wastes from entrance to disposal units and for maintenance and monitoring. To assure that roads on the site do not interfere with site closure and stabilization plans, they should be designed so that construction equipment and other anticipated vehicle traffic will not damage monitoring stations or completed disposal areas during normal operational activities. Roads should be of sufficient width and durability that vehicles may be safely operated on the roads without damaging nearby disposal units which are operating or have been closed. Road surfaces should be designed to prevent concentrated infiltration or runoff which would interfere with other design objectives, i.e., minimizing infiltration, providing a stable site surface and establishing a vegetative cover.

f. A repair shop should be provided and should include tools and facilities for maintenance and repair of operating equipment and fabrication, modification, or repair of special devices, equipment, or sampling and testing equipment.

g. An overpack-container fabrication and storage area may or may not be necessary or desirable, depending on the plan of operations and customer needs.

h. A testing laboratory should be provided and should include necessary testing equipment and computer facilities for storage, retrieval, plotting, and analysis of test and monitoring data. It is considered important to have these facilities on site to avoid delays between sampling, testing, and analysis. In this way, the site manager and his staff can quickly detect any abnormalities or trends that might develop and take action as needed to correct them.

i. A truck decontamination facility is recommended. The wastewater must be properly treated and disposed of.

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j. Personnel and clothing decontamination facilities should be available.

k. An equipment storage building should be provided.

l. A temporary waste storage area should be available, including unloading facilities, for use in case of temporary shutdown of disposal operations due to inclement weather or during periods of peak waste receipts. This storage area should be designed to minimize contact of rainfall and runoff water with waste packages. A disposal vault could be used for storage.

m. Operating equipment must be available, including some or all of the following:

(1) Pickups and vans for transporting personnel and visitors.

(2) Trucks and trailers for transporting waste packages, construction materials, and heavy equipment.

(3) Front-end-loader/backhoe-excavator to excavate foundations and place drainage material.

(4) Forklift for use in temporary storage and disposal operations if access is through horizontal openings in the vault. A mobile crane would serve this purpose if access were through openings in the roof.

(5) Mobile crane for unloading wastes and for placing them in the disposal vaults if access is through openings in the roof.

(6) Drill rig(s) for exploration boreholes, piezometers, and wells.

The sizes, number required, and even the need for some of the above equipment would be dependent on the operating plan, site conditions, and customer needs.

n. A nominal inventory of spare parts and tools for repairs to vital or emergency equipment is recommended.

o. Surface water management features should include components for collection, transport, and discharge, as necessary to prevent flooding, ponding, and erosion. Pangburn and Pennifill (1982) have discussed the goals of surface water management and provided guidance for achieving these goals.

Accepted practice for management of surface water at commercial shallow land burials sites has been discussed by Tucker (1983), along with recommendations for improved performance. Tucker discussed methods to maximize surface runoff and to minimize infiltration through the cover.

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Some of these recommendations are already being practiced at commercial and DOE disposal sites, and others will probably be adopted as new sites are opened.

These recommendations relate to surface and trench-bottom grading practices, proper trench orientation in relation to surface contours, and progressive and sequential trench construction. Establishment of a vegetative cover is also recommended. Differences in conditions and design requirements are noted for arid regions.

Additional measures could be implemented to improve surface drainage. Most of these measures would add to the disposal expenses, but would reduce long-term maintenance.

Rock-filled or paved drainage ditches would reduce erosion and maintenance problems. Guidelines are given in Tucker (1983) for evaluating the erosion potential of various drainage-ditch profiles and various soil profiles.

Surface grading must direct both overland runoff and roof drainage away from the vault foundations in order to prevent erosive undercutting of the structures. Overland runoff and roof drainage are the primary hazards from water to which an aboveground vault sited outside high-risk floodplains will be subjected.

p. Quality-control testing equipment would be required for various aspects of site construction and operations to ensure adequate performance of all facility components.

q. Monitoring devices should include piezometers, wells, water-sampling devices, air-sampling stations, and weather stations. Sedlett and others (1982) have developed a handbook for environmental monitoring of LLW disposal sites. In addition to traditional monitoring described by Lutton and others (1982a, 1982b, and 1983), for monitoring a shallow-land-burial site, monitoring for an aboveground vault should should take into consideration structural performance and long-term durability of the vault.

Monitoring systems must be in place at the site during the preconstruction site-characterization phase. Those early monitoring efforts should include foundation-movement instrumentation, meteorologic-conditions instrumentation, hydrogeologic monitoring, and water analyses.

In addition to standard meteorological parameters to be monitored such as rainfall and temperature, it will be necessary to sample and analyze chemical quality of precipitation at the site. The potential for acidic-rainfall damage to exposed surfaces of aboveground vaults should be assessed with respect to the long-term integrity of the containment envelope.

Active exterior monitoring devices to be used during site characterization and operations should be those planned for use after the vault is closed so that faulty devices can be replaced and a continuity of data output can be maintained into the postclosure phase. For purposes of comparison and background-

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level determination, the active exterior monitoring program should be in place prior to first placement of LLW.

An extensive period of time will elapse between first construction on an LLW disposal site and final closure of the last disposal unit. During that interval, and especially just prior to site closure, careful quantitative observations should be made of rates of erosion, rates of ground motion, and the nature of those evolutions over the entire site. Knowledge of erosion rates will allow estimation of potential soil undercutting or deposition involving the aboveground vaults. Ground motion in large masses could include generalized soil swelling, regional subsidence or localized slope failures. Both erosion rates and gross ground motions can be results of construction activity, so the evolution of those rates and motions is an important indicator of future site stability. The observations made in the years or decades of operation should be extrapolated to the full service life of the disposal units and mitigative measures taken against future adverse effects such as erosion and ground movement before site closure. The monitoring instruments used to measure these phenomena should be rugged and reliable over extended periods of time. When possible, monitoring locations should be chosen that allow for periodic repair or replacement of monitoring devices as necessary.

r. Disposal-unit components are discussed individually below. Design and construction details may vary for these components. One concept of an aboveground vault disposal unit is shown in Figure 3.

(1) Drainage Layer. A drainage layer below the vault may not be required or desirable under some conditions. If a drainage layer is specified, it should be designed for long-term performance. The drainage layer should be graded to consist of various grain sizes and should be compacted to form a stable base for the vault foundation and slab. Three drainage-layer concepts are shown in Figures 1, 3, and 4.

(2) Vault floor. The vault floor may be natural or treated geological materials or engineered materials. Figure 1 shows a concrete floor with an internal drain. Figure 4 is another example of an aboveground vault floor, illustrating multiple barriers to radionuclide migration and a catchment drain. Possible options for earth floors are discussed in the report on belowground vaults (Warriner and Bennett, 1985).

(3) Vault walls and roof. An aboveground vault must support its own weight and the loads imposed by construction and waste emplacement. Walls and roof should be designed to resist accidental impact loads and loads imposed by wind, ice, and snow. The potential adverse impacts of freeze-thaw and chemical

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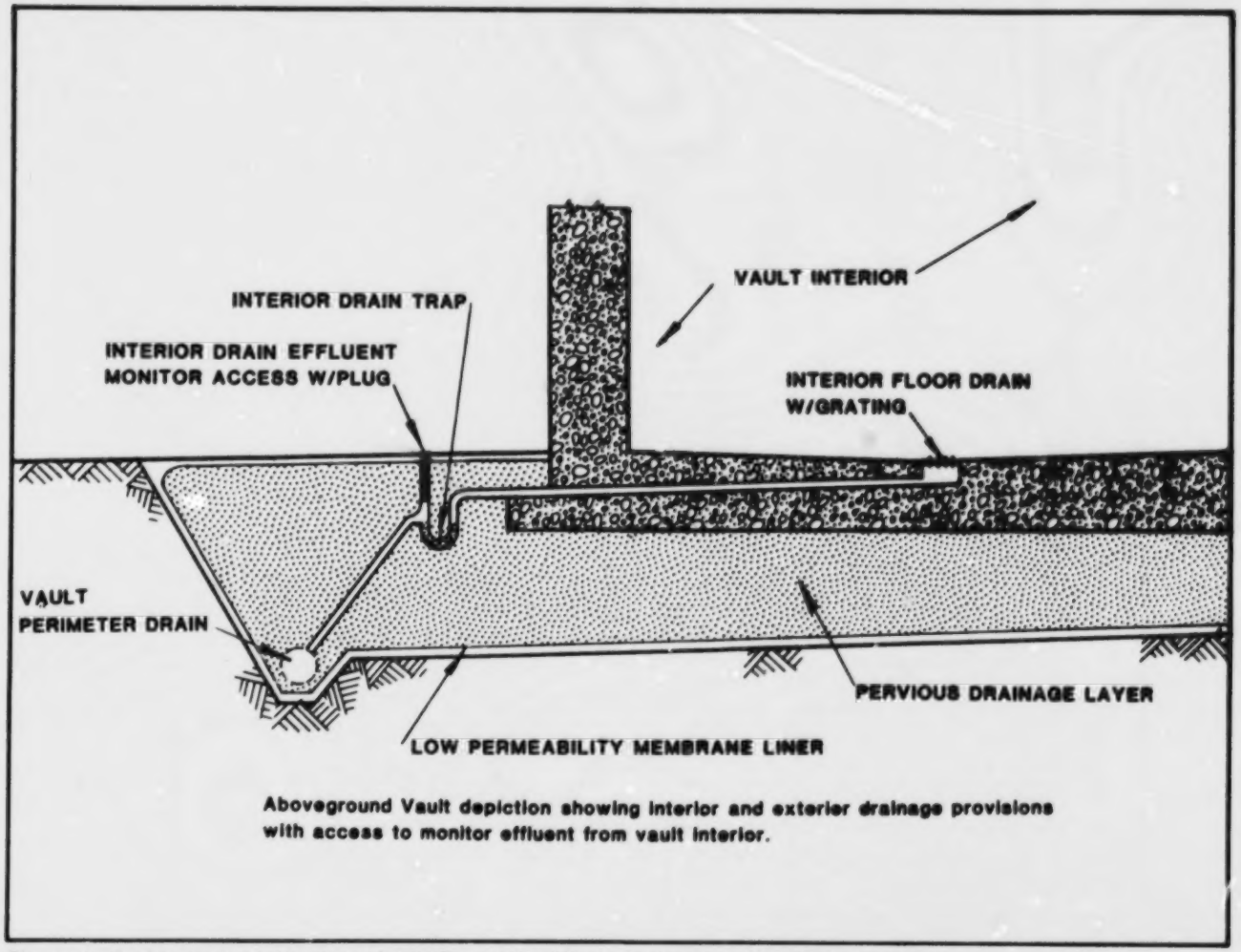

Figure 1. Conceptual combination of interior and subfloor drainage and monitoring station for aboveground LLW disposal vaults

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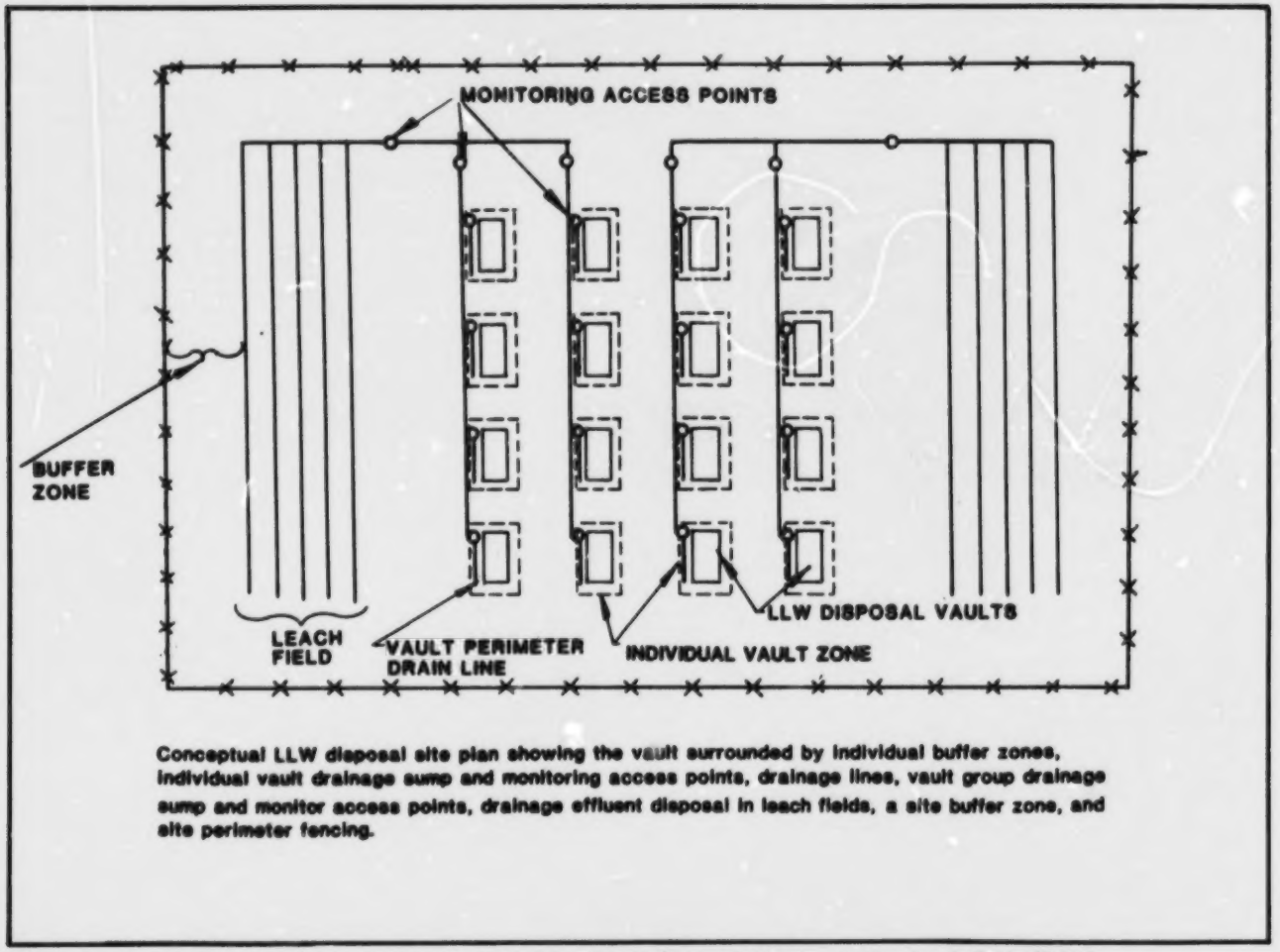

Conceptual LLW disposal site plan showing the vault surrounded by individual buffer zones, individual vault drainage sump and monitoring access points, drainage lines, vault group drainage sump and monitor access points, drainage effluent disposal in leach fields, a site buffer zone, and site perimeter fencing.

Figure 2. Conceptual LLW disposal site plan incorporating engineered structural units, leach field effluent disposal, and effluent monitoring points

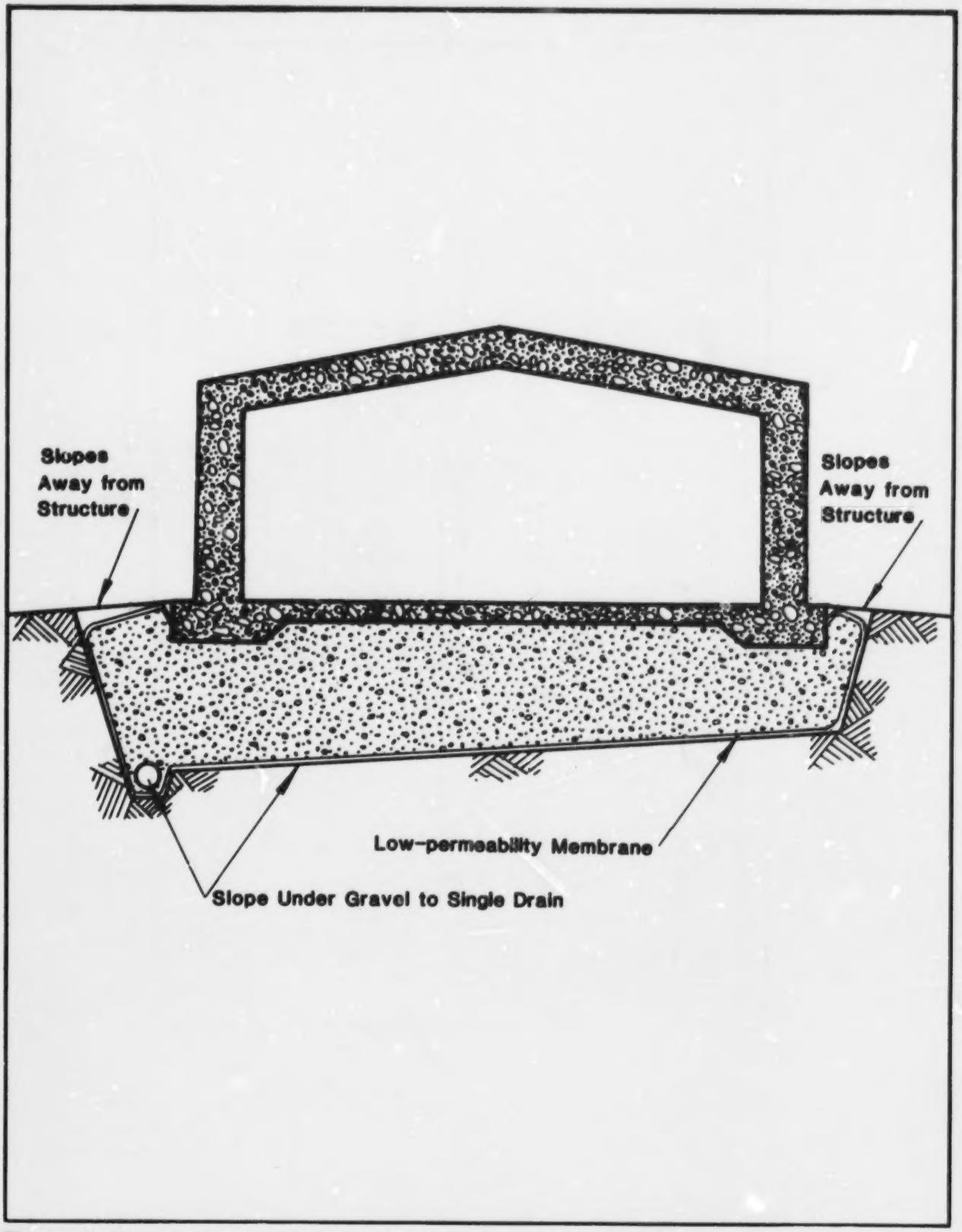

Figure 3. Generic aboveground LLW disposal vault and foundation cross section showing gravel drainage layer, low permeability membrane, sloped excavation, and peripheral subsurface drain

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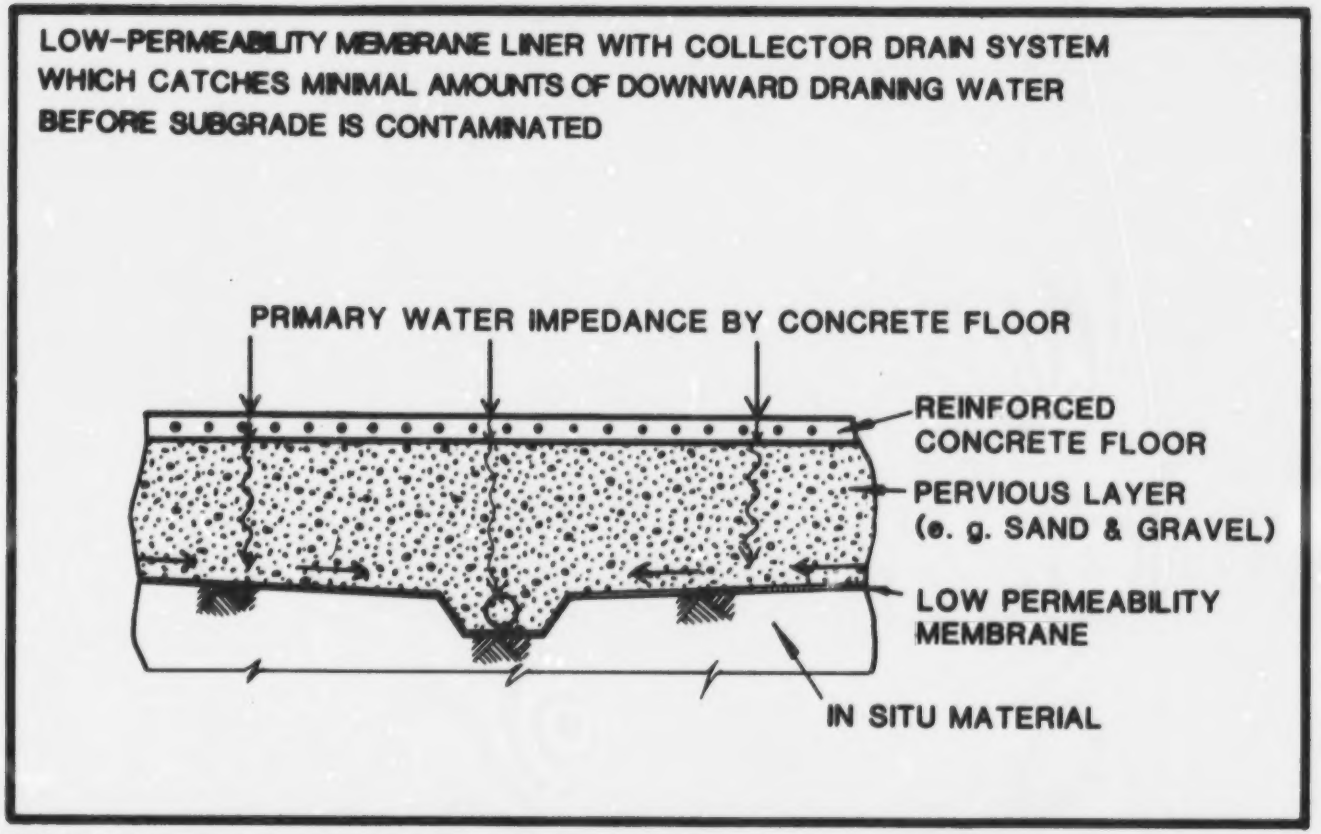

Figure 4. Example of aboveground LLW disposal vault floor cross section showing one concept for concrete floor, gravel drainage layer, low permeability membrane, and sub-floor drain

attack should be assessed in the design, as well as potential impacts from ongoing construction and operations. Openings in walls or roof for waste emplacement, inspection, or venting or draining must be carefully designed to resist stress concentrations or impact loads from operations and to allow for temporary and final disposal-unit closure. Figure 5 illustrates one concept for access through wall openings and a closure of these openings.

(4) Vault interior drains. Interior drains provide means to remove any waste that enters the vault or condenses within the vault. Drains should be designed to prevent uncontrolled release of water and radionuclides. One possible method to achieve this is shown in Figure 1. Considerations important in the design and use of vault drains include the avoidance of the need for active maintenance, the need to monitor the drain effluent, and the need for a plan of action should problems be observed.

The floor drains should pass collected water by gravity to a central point for sampling and testing and then into the main surface drainage system, such as shown in Figures 1 and 2. Gravity flow is recommended to avoid active maintenance of pumps. Drainage effluent should be disposed of within the site. One concept for effluent disposal shown in Figure 2 would use leach fields.

The drains should resist biotic intrusion, require only minimal maintenance, and be capable of being sealed. The drains should be monitored during the operational period and for some period after closure. The drains should be specifically included in long-term plans for maintenance of the site.

(5) Vents. An aboveground vault may exhibit interior temperatures higher and lower than outside air temperatures during parts of each year. In humid climates, natural atmospheric humidity will then result in condensation occurring inside the vault. Unless means are provided for disposing of such condensate, the water will accumulate around the waste packages.

Another potential problem is the occurrence of liquid gaseous by-products of decomposition of wastes.

Floor drains may be a better method for disposing of condensate and other liquids, but drains are not suitable for removing gases from the vault interior. If vents are used for this purpose, ongoing active maintenance is a likely requirement during and after the operations period.

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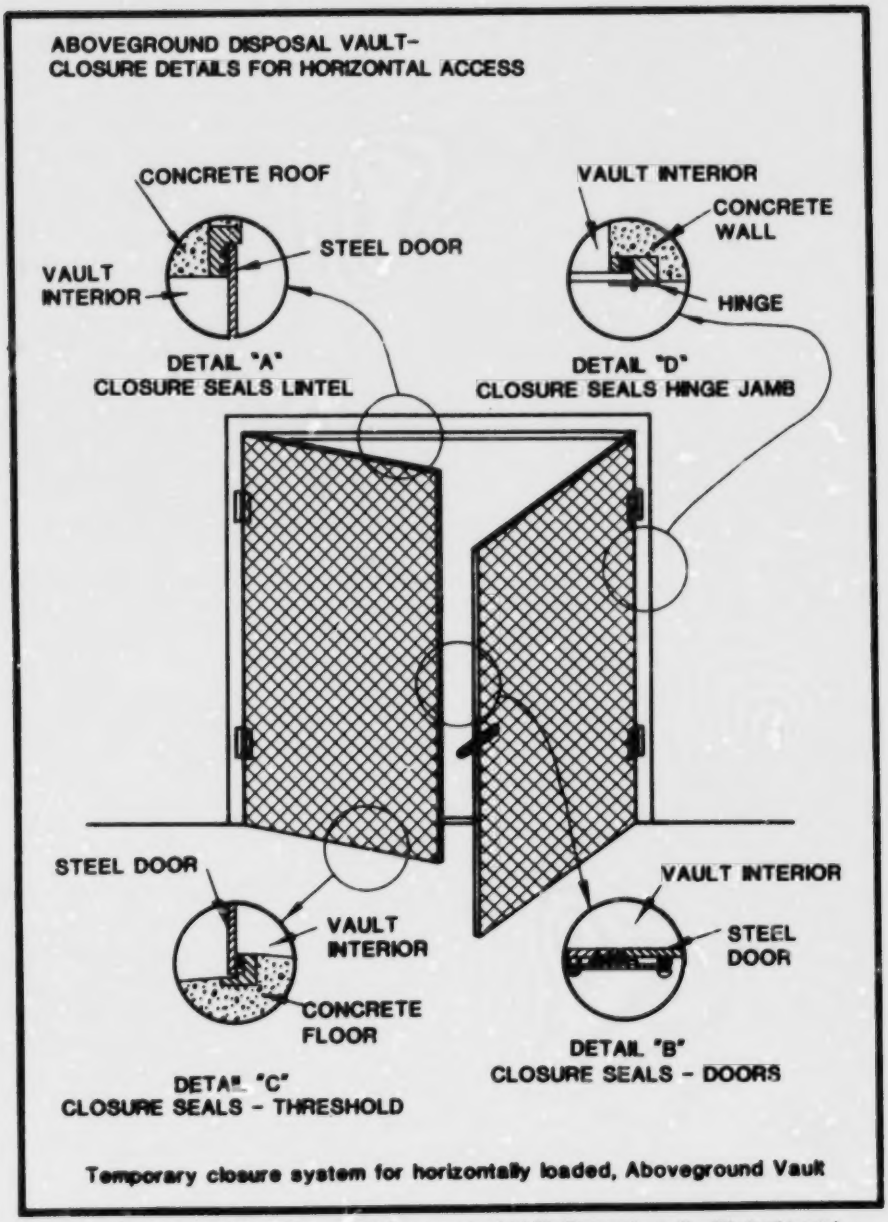

Figure 8. One concept for closure of aboveground LLW disposal vault with horizontal access for waste emplacement. Permanent closure is accomplished by welding doors shut

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2.4 Performance Capabilities

An aboveground vault for low-level radioactive waste disposal is an engineered structure that must satisfy the performance objectives through its own design features, because there are no additional barriers to radionuclide migration, inadvertent intrusion, or attack from climatic extremes.

Current geotechnical foundation-engineering and structural-design methods allow aboveground vaults to be built to withstand a large range of natural hazards, including seismic events, erosion, and landslides. Aboveground vaults are less vulnerable to flood damage. Physical security can be engineered into aboveground vaults. Appropriate design of the vault closure should render the portals at least as secure as the bulk of the structure so that inadvertent intrusion will be prevented. The high visibility of aboveground vaults is a likely deterrent to inadvertent human intrusion. These qualities may allow more freedom in siting vault disposal facilities in regions that demonstrate less than ideal characteristics for other disposal methods.

Interfaces between different construction materials can be sealed to impede radionuclide migration. Long-term performance of joints, as well as the rest of the structure, must be assured through careful design and construction and through performance monitoring.

Venting or even eventual retrieval of the waste material can be designed into the original structure or accomplished at some future date without jeopardizing the performance objectives. Monitoring of aboveground vaults is enhanced by their accessibility.

Because the disposal units are aboveground, there are several design considerations for belowground disposal that are less applicable to this method. For example, earth overburden loads are not a necessary design consideration, nor is ponding or ground-water intrusion. Aboveground vaults are less susceptible than belowground disposal facilities to plant or animal intrusion.

Standardization of vault design, construction, and operation, keyed to a specific site, may enhance safety and efficient operations as a result of worker familiarization with waste-handling procedures. However, standardization to try to accommodate all sites is not recommended.

Some disadvantages may be expected with aboveground vault disposal. As mentioned, there would be no secondary geological barrier to prevent radionuclide releases to the atmosphere if the vault structure failed after the waste packages deteriorate. Also, there would be less time available to take remedial actions to prevent radioactivity releases to the atmosphere. It is reasonable to expect that an aboveground vault facility, subjected to long-term exposure to the elements of wind, water, and temperature extremes, will require ongoing active maintenance and periodic repairs. These active maintenance requirements could be extensive. Methods and materials are available to reduce the frequency and extent of such maintenance and repairs, but not to

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eliminate the requirement. The authors believe this should be an important consideration in the determination of the feasibility of this disposal method. For this reason, the institutional control period required would be much longer than for any subsurface disposal method.

Also, exposure of workers to radiation hazards of high-activity wastes could be higher than desired unless remote-handling equipment is used.

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3. TECHNICAL REQUIREMENTS FOR ABOVEGROUND VAULT DISPOSAL OF LLW

In this section, the technical requirements thought to be necessary for evaluation of site suitability, design, operations, closure, and monitoring are assessed.

The pattern of development used for each section is:

a. First, each existing criterion for near-surface disposal is quoted, including the subparagraph number of 10 CFR Part 61 Subpart D under which it appears.

b. The criterion is discussed and judged as to its relevance to aboveground vault disposal.

c. A recommendation is made to:

(1) Retain the criterion as is,

(2) Not apply the criterion to the evaluation of this alternative, or

(3) Modify the criterion to make it applicable to this alternative.

Any departures or changes in recommendations from the position taken in the Task 1 report (Bennett and others, 1984) are explained.

At the end of each section (site suitability, design, operations and closure, and monitoring) technical issues implied within 10 CFR 61.12 which should be addressed but which are not covered by existing criteria or recommended modifications are discussed. Specific criteria, in prescriptive language, are not given. Rather the points that should be addressed and the reasoning behind them are stated. This method of presentation is thought to be more appropriate than offering specific criteria, as it allows the NRC to consider those issues and develop specific wording that it considers appropriate on a point-by-point basis. Alternatively, the NRC may wish to provide regulatory guidance, as appropriate, without changing or adding to the existing criteria.

3.1 Site Suitability

3.1.1 Role of Site Characteristics

As mentioned in section 2, the aboveground vault does not rely as much on site characteristics as other disposal methods to meet the performance objectives. The vault structure itself, through careful design and construction, must meet most of these.

However, site characteristics do play a role in the design and construction of aboveground vaults. Characteristics of the disposal site and surrounding vicinity which must be determined include, but are not necessarily limited to,

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geological, geomechanical, hydrological, meteorological, and climatological characteristics. These characteristics are discussed below.

3.1.1.1 Geological and Geomechanical Characteristics

A regional geological framework, including the stratigraphy, tectonics, structure, and physiography, must be established for a proposed site. Detailed geologic information, required for site modeling, may be obtained from existing reports, surface mapping, exploratory boreholes, surficial geophysical surveys, borehole geophysical logging, and test pit excavations.

Geomechanical characteristics of the site soil and rock deposits are required for design and analyses. Performance parameters such as the coefficient of consolidation, permeability, cohesion, angle of internal friction, unconfined compressive strength, and deformation modulus should be determined, as appropriate, for the soil and rock types. Index properties, such as water contents, unit weights, Atterberg limits, Standard Penetration Test (SPT) blow counts, cone penetration resistance, particle-size distribution, void ratio, organic content, and Rock Quality Designation (RQD) should be determined for classification as well as design purposes. Bearing capacity and settlement should be predicted from appropriate soil properties, structural loads, and layout.

3.1.1.2 Hydrological Characteristics

If the vault envelope performs satisfactorily, surface water and ground water represent the most significant pathways for potential long-term releases to the general population. Therefore, proper characterization of the hydrological conditions is required including both site-specific and regional data. Surface-water studies should include aerial photography and topographic mapping, as well as the determination of drainage areas, flood flow frequencies, runoff rates, infiltration rates, flow rates, and flow volumes.

To define the hydrological and stratigraphic framework, site-characterization studies should be performed to identify and characterize the separate hydrogeologic units underlying the site, including their lithology, thickness, lateral extent, continuity, inclination, areas and modes of recharge and discharge, piezometric levels, hydrochemistry, interrelationship with adjacent hydrogeologic units, and interrelationship with surface water bodies.

The hydrological characteristics of the site should be used to develop flow and transport models with which migration of potential releases may be evaluated. In addition to modeling the surface and subsurface hydrology, ground-truth documentation should be obtained by laboratory and field tests. Data-collection or sampling points should be established which will not only verify model predictions, but may continue to be used throughout the design and construction phases and, eventually, for long-term monitoring.

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3.1.1.3 Meteorological and Climatological Characteristics

The aboveground vault will be vulnerable to all climatic conditions and extremes occurring during its service life because it is exposed to the surface environment. Metallic components will suffer corrosion, plastic or organic components will suffer oxidation and sunlight-caused chemical degradation, and concrete will be attacked by freeze-thaw stresses and abrasion and airborne acid attack. Vaults of any material aboveground will be exposed to wind and precipitation. Exposure to the weather is the single greatest natural hazard to an aboveground vault, regardless of the quality of engineering design and construction.

The extremes of temperature and precipitation that are exhibited by records applicable to the site are to be the starting points for characterizing the climatology of an aboveground vault site. Using deductions from prerecorded pieces of evidence (e.g., vegetative evidence, stream-course morphology) and using climate-prediction models, the recorded extremes must be extrapolated through the end of the performance period. It is unlikely that an extreme climatic event will occur during the period of preconstruction monitoring, so the historical and deduced prehistoric data will be of greatest use. Preconstruction monitoring will, however, be the only source of information for rainfall acidity and other ongoing "new" climatic perturbations. Upwind sources of atmospheric contaminants must be located, possibly at great distances from the actual site. Because those sources cannot to be eliminated, their effects at the site must be defined during site characterization and accounted for in unit design.

3.1.1.4 Seismological Characteristics

As an engineered structure, a vault may incorporate design safeguards against damage from earthquake-induced ground motions and may be sited in a region of finite risk of earthquake occurrence. This capability is one of the important advantages of an engineered aboveground vault for LLW disposal. To exercise the freedom of siting a vault in a seismic risk zone, however, it is imperative that the proposed site be characterized in terms of the probable seismically-induced ground motions - their amplitudes, wave lengths, duration, and frequency of probable occurrence. The maximum probable earthquake magnitude and its associated intensity at the site for the life of the radionuclide containment should be used as the prediction earthquake when determining ground motions and survivability of the engineered disposal unit.

3.1.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal-site suitability are contained in 10 CFR Part 61 Subpart D, paragraph 61.50.

Criterion 61.50 (a)(1) states: "The purpose of this section is to specify the minimum characteristics a disposal site must have to be acceptable for use as a near-surface disposal facility. The primary emphasis in disposal site

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suitability is given to isolation of wastes, a matter having long-term impacts, and to disposal site features that ensure that the long-term performance objectives of Subpart C of this part are met, as opposed to short-term convenience or benefits."

Discussion. Aboveground vault disposal does not rely as heavily on site characteristics as does near-surface belowground disposal, even though the methods are similar in some respects. Design features play a more important role in satisfaction of the performance objectives for aboveground disposal. Therefore, the minimum characteristics a disposal site must have to be acceptable for use as an aboveground vault disposal facility may be less restrictive than for near-surface belowground disposal. However, the emphasis on isolation of wastes and the long-term satisfaction of the performance objectives is constant for any disposal method.

Therefore, the emphasis on site suitability must be shifted to the assessment of impacts that site characteristics will have on design features. For this alternative, it is the design features that must ensure long-term satisfaction of the performance objectives.

Recommendation. This criterion states the goal of all subsequent site suitability criteria. Though the emphasis must be shifted to design features for aboveground vault disposal, the goal is valid. Therefore, the criterion should be retained.

Criterion 10 CFR 61.50 (a)(2) states: "The disposal site shall be capable of being characterized, modeled, analyzed, and monitored.

Discussion. The criterion is necessary to ensure that the long-term performance objectives are met. While the wording seems deceptively simple, the underlying issue is not. Many rather clever analytical tools have been developed to model natural systems, e.g., 2-D and 3-D computer simulations for analysis of ground-water movement, and sophisticated analyses of slope stability.

However, all models and analyses depend on sound judgment and reliable input data (strengths, permeability, depth to water table, etc.) to reach correct solutions.

In general, the more variable data are, the less reliable are our inferences and judgments about them. Specifically, the site should be geologically simple so that site characterization, modeling, and analysis are not too complex. The NRC staff (Siefken and others, 1982) has pointed out that models tend to homogenize stratigraphic units and average the hydrologic properties to satisfy assumptions and boundary conditions. Therefore, the site characteristics used as model inputs must vary over a sufficiently narrow range so that the simplified inputs and assumptions are valid. Sedlett and others (1982), Cherry, Grisak, and Jackson (1974), and Cherry and Gilham (1977) have discussed this issue and indicated that monitoring to measure the necessary site characteristics is much more complex and less reliable for geologically

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complex sites. Sedlett and others indicated that it may be impossible to get adequate, reliable data from sites underlain by fractured rock. Even sophisticated, expensive site investigations sample only a small fraction of the subsurface, so extrapolation over wide areas at highly variable sites is unreliable.

Simply put, the more uniform the site and the natural processes occurring on it, the less complex and costly the site investigation may be, and the more reliable predictions may be.

In addition to site modeling, the vault should be modeled to determine its response to normal and unusual loads and events to ensure satisfactory structural performance.

Recommendations. This criterion should be retained as is.

Criterion 61.50 (a)(3) states: "Within the region or state where the facility is to be located, a disposal site should be selected so that projected population growth and future developments are not likely to affect the ability of the disposal facility to meet the performance objectives of Subpart C of this part.

Discussion. The objectives of this criterion are to minimize the risks of exposure of the general population to releases of radioactivity and to minimize the risks of inadvertent intrusion. Census data and urban-planning studies should be analyzed to develop site-specific population and development predictions. However, it is unlikely that the data and projections from existing planning studies would be reliable for long-term projections. Most forecasts are relatively short-term (50 years or less). Extrapolation of short-term projections to 100 to 500 years into the future is speculative at best. Therefore, while the goal of the criterion is a valid one, it may be difficult to implement reliably for any disposal method.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(4) states: "Areas must be avoided having known natural resources which, if exploited, would result in failure to meet the performance objectives of Subpart C of this part."

Discussion. The goal of this criterion is to avoid the possibility of compromising site integrity caused by future exploration or exploitation of the natural resources adjacent to or underlying the disposal site. An example would be deep borings for oil exploration. Another example is a deep water well. Such wells, if pumped for long periods at rates much higher than the ground-water recharge rates, can cause surface subsidence and cracking of the surface. This phenomenon is a serious problem in parts of the arid southwestern U.S.

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Recommendation. The criterion should be retained as is. Practical application of the criterion is not likely to preclude or significantly limit the selection of suitable sites within a given region or state.

Criterion 10 CFR 61.50 (a)(5) states: "The disposal site must be generally well drained and free of areas of flooding or frequent ponding. Waste disposal shall not take place in a 100-year floodplain, coastal high-hazard area or wetland, as defined in Executive Order 11988, "Floodplain Management Guidelines."

Discussion. The desirability of a well-drained site free of areas of flooding or frequent ponding can be readily understood for the operations phase. Equipment could be damaged or immobilized, making it impossible to take damage-prevention or remedial measures. Vault foundations could be eroded or weakened.

The probability of occurrence and severity of the above problems can be estimated, based on the frequency and extent of a flood event at a specific site and appropriate hydrological models.

The second part of the criterion, which prescribes avoidance of legally defined flood-prone areas, is achievable using existing topographic maps and rainfall and runoff data.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(6) states: "Upstream drainage areas must be minimized to decrease the amount of runoff which could erode or inundate waste disposal units."

Discussion. Unlike the previous criterion, which prescribed avoidance of legally defined flood-prone lowland areas, the above criterion has as its primary goal the prevention or minimization of damage from flash-flood situations. This situation is more likely in areas of greater topographic relief. The criterion, therefore, implies that the disposal units should be located on high ground, i.e., the ridgetops and plateaus, but protected valleys or relatively flat lands are not excluded. It could be implied that aboveground vaults may be less vulnerable to inundation. However, the objective is still valid.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.50 (a)(7) states: "The disposal site must provide sufficient depth to the water table that ground-water intrusion, perennial or otherwise, into the waste will not occur. The Commission will consider an exception to this requirement to allow disposal below the water table if it can be conclusively shown that disposal site characteristics will result in molecular diffusion being the predominant means of radionuclide movement and the rate of movement will result in the performance objectives of Subpart C of

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this part being met. In no case will waste disposal be permitted in the zone of fluctuation of the water table."

Discussion. The goal of this requirement is to avoid contact of waste packages and ground water. Ground water is considered to be the major pathway of release in humid areas. Contact of water and waste packages also hastens the rate of package deterioration and radionuclide migration. The criterion does not specify the depth between the water table and the disposal unit. This depth must be determined from measurement and analysis of site characteristics. These characteristics include the coefficient of permeability, the degree of homogeneity of the site soil and rock deposits, whether preferential flow paths exist, and the degree of fluctuation of the water table. The impacts of present and projected land uses on the regional water table should also be considered in addressing this criterion.

The possible exception within the criterion to allow disposal below the water table cannot be applied to this alternative since the disposal unit is entirely aboveground.

Recommendation. The criterion is applicable to disposal of LLW in aboveground vaults and should be retained. The exception for below-water-table disposal cannot be applied. Since the ground-water pathway is so important in the assessment of disposal-site performance in humid regions, this criterion is considered to be a crucial test for site suitability. This recommendation differs from the position stated in the Task 1 report, in which it was pointed out that aboveground vaults are, by definition, above the water table. However, the objective of the criterion is still valid and can be met.

Criterion 10 CFR 61.50 (a)(8) states: "The hydrogeologic unit used for disposal shall not discharge ground water to the surface within the disposal site."

Discussion. As pointed out in the Task 1 report, since an aboveground vault is not in a hydrogeologic unit, the wording of the criterion is not entirely appropriate. However, the goal of the criterion is valid. Location of a disposal unit over a formation that discharged ground water to the surface within or even near the site should be considered unsafe and unnecessary. It is relatively simple to uncover evidence of springs early in the site investigation. Such occurrences should be grounds for exclusion of that particular site from further consideration.

Recommendation. The criterion should be retained. Though the requirement could be phrased more appropriately for this alternative, its purpose is clear and valid.

Criterion 10 CFR 61.50 (a)(9) states: "Areas must be avoided where tectonic processes such as faulting, folding, seismic activity, or vulcanism may occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

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Discussion. The performance objectives to which this criterion refer are equally applicable to any LLW disposal alternative. However, the degree to which occurrence of a tectonic process might impair disposal-site performance would vary significantly for different concepts.

Krinitzsky (1973-1985) and Boore and others (1978) describe the evaluation and assessment process necessary to define seismic risks at a locality. Coulter and others (1972) and Allen (1976) describe site-specific geologic considerations in earthquake hazard analysis. Newmark and Rosenbleuth (1971), Newmark and Hall (1973), and Dowrick (1977) describe procedures for designing seismic-hazard resistance into aboveground structures. The state of the art exists in both engineering-design and construction practice to utilize LLW disposal sites that demonstrate finite (greater than zero) levels of seismic hazard without compromising satisfaction of the Subpart C performance objectives. The key to the use of such sites for aboveground vault disposal units is that the uncertainties of reliance on in situ materials for containment are minimized and confidence in structural integrity can be placed in the proper application of engineering expertise. Because a disposal unit is essentially a passive structure, compared to an active structure like a nuclear power plant, there is more freedom in exercising engineering designs to allow use of sites having some finite level of seismic hazard. It is emphasized that the risk must be quantified for a design-basis natural event.

Recommendation. The criterion should be retained as is and can be satisfied without eliminating significant areas that would otherwise be suitable.

Criterion 10 CFR 61.50 (a)(10) states: "Areas must be avoided where surface geologic processes such as mass wasting, erosion, slumping, landsliding, or weathering occur with such frequency and extent to significantly affect the ability of the disposal site to meet the performance objectives of Subpart C of this part, or may preclude defensible modeling and prediction of long-term impacts."

Discussion. The goal of this criterion is valid. Serious erosion could damage the vault foundation if left uncorrected. Slumping soils and landslides could crack or destroy vault slabs and walls, drainage layers, or monitoring wells. Weathering of site geologic materials can result in swelling and increased erosion. Areas undergoing rapid geological processes can usually be identified during the screening process through analysis of aerial photographs taken a few years to tens of years apart. Such areas can be eliminated at this stage without seriously limiting the availability of suitable sites within a state or region.

Recommendation. The criterion should be retained as is. This recommendation differs from the position stated in the Task 1 report. The recommended modifications stated in the Task 1 report are discussed under Section 3.1.3 below. These issues are not properly described as surface geological processes.

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Criterion 10 CFR 61.50 (a)(11) states: "The disposal site must not be located where nearby facilities or activities could adversely impact the ability of the site to meet the performance objectives of Subpart C of this part or significantly mask the environmental monitoring program."

Discussion. This requirement is generally applicable to any LLW disposal facility. It does not preclude selection of a disposal site near other facilities. It does require an assessment of the potential adverse impacts of such a decision. This assessment can only be made on a site-specific basis.

Recommendation. The criterion should be retained as is. Because of the site-specific nature of this requirement, the criterion must be general in its wording.

3.1.3 Suggested Additional Technical Considerations

Additional technical considerations for demonstrating site suitability should include requirements to determine the existence and potential adverse impacts of dispersive soils, liquefiable soils, corrosive soils, expansive soils, karstic or cavernous areas, and areas of land subsidence at a potential disposal site. The potential problems caused by occurrence of such deposits or conditions are discussed below.

3.1.3.1 Dispersive Soils

The occurrence of dispersive soil deposits below or near the disposal site can result in accelerated erosion, piping, and collapse of the surface.

Pinhole erosion tests can provide evidence of the susceptibility of soils to dispersion (Sherard and others, 1976). High percentage (greater than 60 percent) of sodium in total dissolved salts is also an indicator of dispersive clays. Dispersive soils cannot be identified by conventional index tests such as Atterberg limits or particle size distribution (Perry, 1979). Visual inspection of cut slopes and embankments can uncover dispersive-soil problems. Visual inspection is not very helpful for undisturbed sites because dispersive clays are usually not present in topsoil due to the process of eluviation (movement of clay particles downward in the soil profile). Therefore, natural deposits may show little or no evidence from surface appearances that the underlying soil may be dispersive. The piping channels that develop in the underlying soil can be obscured by the vegetative cover and bridging of the topsoil deposit. Eventually, this top layer will collapse into the hole as erosion damage progresses. In excavated slopes and man-made embankments, the dispersive characteristics are more readily observable. Excavated slopes in dispersive clays exhibit rill erosion, surface cracking, and vertical erosion tunnels resembling badlands topography (Perry, 1979). Embankments constructed of dispersive clays, even with good vegetative cover, also develop rainfall erosion tunnels called cave-ins or jugs. In the authors' opinion, the primary risk to disposal vaults constructed over dispersive soil is from piping erosion. If the infiltrating water exits beneath the foundation along

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the side slope of a ridge, the erosion could undermine the foundation, lead to local instability of the slope, and ultimately to failure.

Measures are available to avoid problems if the dispersive nature of the soil is recognized before construction. For example, sand filters can be used to seal and safely control leaks in dispersive clays. Lime treatment has also proved effective in reducing tunnel erosion in dispersive-clay dams (Forsythe, 1977; Phillips, 1977; and Rosewell, 1977). The calcium in lime is believed to result in a significant reduction in shrinkage and a lower percentage of exchangeable sodium (and a higher percentage of exchangeable calcium) actually going into solution, thereby reducing the dispersive erosion.

3.1.3.2 Corrosive Soils

The occurrence of corrosive soils in humid areas could result in deterioration of disposal-unit floors, footings, drains, and waste packages. As discussed in Appendix A, high soil acidity, substantial soil moisture, and dissolved calcium ions contribute to long-term corrosion of concrete. Metallic corrosion is most serious in the presence of high soil electrical conductivities, substantial soil moisture, and high dissolved ion contents. The potential risk to both concrete and metal from corrosive soils is much smaller in arid regions.

Chemical analyses can be used to determine whether a potential problem exists. If so, design and construction measures can be implemented to reduce the impact, such as the use of sulfate-resistant concrete. In the authors' opinion, otherwise suitable sites should not be disqualified on the basis of occurrence of corrosive soils alone.

3.1.3.3 Solution Cavities

Solution cavities are formed in carbonate and sulfate rocks such as limestone, dolomite, marble, and gypsum by the action of slowly moving ground water, which dissolves the rock, first to enlarge fractures and then to form tunnels and caves. Most of the caves in the world, including the largest, are of this type. A general term for regions where such phenomena are common is "karst". Disposal above carbonate formations that are actively being dissolved should be avoided. Solution cavities can result in collapse of overlying strata which may serve as aquicludes or provide support for vault foundations.

The occurrence of solution cavities can also result in significant unpredictable alteration of ground-water seepage patterns and quantities which would preclude reliable modeling. Because of their discrete locations, the probability of locating solution cavities through normal site investigations is low. Geophysical methods have been successful in some cases. With borings, it is literally a hit or miss situation. Obviously, the probability of missing an existing cavity is higher than that of hitting it. Even if they are reliably located, solution caverns must be grouted to fill the voids. It is

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costly and difficult to fill completely all voids and impossible to ensure that solutioning will not continue adjacent to the grouted interface.

Regional geological data can provide general evidence to indicate the occurrence, depth, and lateral extent of formations known to be susceptible to occurrence of solution cavities. These karstic areas should in general be avoided.

3.1.3.4 Liquefiable Soil

Liquefaction of soils is the transformation from a solid to a liquefied state as a consequence of increased pore-water pressure, and results in the loss of effective shear strength. Liquefaction of sand deposits has caused extensive damage in numerous seismically active areas of the world, e.g., Japan, Alaska, and California. Less publicized cases of liquefaction of sensitive clays have also caused extensive damage in Norway where marine deposits have liquefied after only minor disturbances. These occurrences were preceded by leaching of salts in the clay by ground water moving downward from mountainous areas to the sea. These clays lose strength as the salts are removed, and in many locations near the sea, a state of near equilibrium exists. Even minor disturbances, such as excavating a building foundation or a farm pond, have been known to initiate liquefaction of these deposits. Once started, wide areas can be progressively affected.

The potential risk to LLW disposal facilities from liquefaction is small, because most sites with liquefiable deposits have other characteristics that make them undesirable. For example, the site may be near a coastal high-hazard area or area of high soil permeability. The main danger would be the failure to recognize the liquefaction potential of deposits below the disposal vault.

3.1.3.5 Expansive Soils

Volume change of expansive-soil subgrades resulting from moisture variations frequently causes severe pavement damage. Highways constructed in the Southwest, Western Mountain, Central Plains, and Southeast geographical areas are particularly susceptible to this type of damage.

A 1972 survey (Lamb and Hanna, 1973) of all the 50 states, Puerto Rico, and the District of Columbia indicated that 36 states have expansive soils. Expansive soils occur so extensively within parts of the US that alteration of highway routes to avoid the material is virtually impossible. The annual cost of damage to streets and highways caused by expansive soils was estimated in 1973 to exceed $1.14 billion (Jones and Holtz, 1973).

Additional damage to slab-on-grade buildings was not estimated but was and is substantial. Although this damage is of much concern to state and Federal highway officials and local building officials, expansive-clay problems do not occur in every state. Likewise, problems do not occur uniformly over areas in which expansive soils are found. The key geological factors in determining a

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geologic unit's expansive nature or "swell potential" are clay mineralogy and amount of clay or shale within a geologic unit. Clay mineralogy, specifically montmorillonite content, can be used to estimate the degree of expansiveness; the frequency of occurrence can be related to the amount of clay or shale in the geologic unit (Snethen, 1979a, 1979b).

One other essential factor that determines whether expansion actually occurs is the availability of water. Without water the soil will not swell. Likewise, if water is available year round, the soil will swell to its full potential under existing loading conditions and no further volume change will occur. Consequently, the damage caused by expansive soils occurs primarily from volume changes near the surface within the zone of seasonal soil-moisture changes.

Damage usually takes the form of buckled, warped, and heaved slabs, cracked concrete or masonry walls, and general distortion of the structure. For the case of aboveground vault disposal facilities, damage is likely to occur if concrete slabs are cast in direct contact with expansive clays. The potential for damage is exacerbated if the slab is cast over an excavation or cut, because the soil has been unloaded by the excavation and the moisture equilibrium has been disturbed.

Methods are available to minimize or prevent damage from expansive soils. For example, form voids made of heavy corrugated paper are sometimes used beneath slabs to allow space for the soil to swell without damage. The slab must be supported on reinforced grade beams, founded on piers that extend below the zone of seasonal moisture change. The grade beams must not be in direct contact with the surface soil. End-bearing piers founded within the zone of moisture change may heave upward because of the high swelling pressures. The opposite problem of piers settling significantly because of negative skin friction as the clay desiccates during dry periods can also occur. This problem can dealt with by providing a low-friction membrane between the pier and soil to reduce skin friction.

However, all the engineering fixes have two things in common. They rely on discovery of the expansive nature of the soil before construction, and they add to the construction cost.

The Federal Highway Administration has published a series of reports describing research conducted to identify problem areas within the US and to develop remedies where feasible (Snethen and others, 1975; Patrick and Snethen, 1976; Snethen, Johnson, and Patrick, 1977a, 1977b; Snethen, 1979a, 1979b). These reports describe methods to characterize the potential for volume change and provide maps showing the occurrence and distribution of expansive soils in the US. Methods are also recommended for minimizing damage from such soils.

3.1.3.6 Land Subsidence

Subsidence is caused by densification of earth materials, collapse of subsurface cavities, plastic outflow of weak materials, and regional downwarps.

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There are several causes of densification of earth materials. They are withdrawal of ground water or petroleum, vibration of granular materials, densification of deltaic deposits, decomposition of organic materials in swamp deposits, artificial compaction of fills and embankments, and surcharging. Collapse of subsurface cavities may occur in karst topography or because of previous mining activities. Examples of plastic outflow of weak materials can be found where fill has been placed above peat bogs and recent lake deposits. Regional downwarps are large-scale subsidence basins and are caused by tectonic, glacial, or volcanic activity.

Subsidence is a gravity-dominated movement, so its principal movement is vertical, but there is always lateral strain associated with subsidence, and both could cause serious damage to engineered disposal units. In some areas, land subsidence has progressed to the point of equilibrium under existing conditions and any further movement would be relatively insignificant, unless the driving forces changed. Equilibrium would have to be established for the site to be suitable. Subsidence caused by underground cavities can be reduced by grouting the cavities. However, this is an expensive operation and is not recommended if the site can be avoided.

Regional geological data should be carefully examined to identify any areas of possible subsidence. Records of any previous mining, oil drilling, or substantial ground-water use should be investigated. These areas should be avoided if evidence of significant ongoing subsidence is found.

3.2 Design

3.2.1 Role of Design Features

The role of design features is to complement the natural site characteristics at the disposal site. The degree of reliance that must be placed in the design features will vary from site to site and even within a site. For the case of aboveground disposal, the degree of reliance which must be placed in design features is greater than for any belowground method. Even so, design features should not be viewed as a means to overcome a site deficiency, unless it can be shown that the design features will be effective over the long term. Rather the design features should enhance or improve the site's satisfactory performance.

Design features include all the components, equipment, and facilities, other than the land itself, used for waste management and disposal at the site. One goal of the design should be to minimize the potential conflicts between construction, operations, and closure activities to ensure compatibility while providing for efficient land use. Design considerations for major components were discussed in Part 2 of this report.

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3.2.2 Assessment of Existing Criteria

The existing criteria for assessment of near-surface disposal-site design are contained in 10 CFR Part 61 Subpart D, paragraph 61.51. Six technical requirements are listed under subparagraph 61.51(a). Subparagraph 61.51(b) is reserved for disposal-site design for other than near-surface disposal. This organization is common to the sections on site suitability, design, and operations and closure.

The criteria are considered one at a time in the following paragraphs. Additional technical considerations that should be addressed are discussed in Section 3.2.3.

Criterion 10 CFR 61.51 (a)(1) states: "Site design features must be directed toward long-term isolation and avoidance of the need for continuing active maintenance after site closure."

Discussion. Features and components of an aboveground vault disposal facility that could enhance long-term isolation of wastes have been discussed in Section 2 of this report. Since the aboveground vault disposal concept relies completely on a single engineered barrier, i.e., the vault envelope, for satisfaction of the performance objectives, great care must be used in the selection of material used and in construction quality control.

Recommendation. The criterion should be retained as is. The requirement of avoidance of the need for long-term active maintenance after site closure is a critical test of satisfactory performance of aboveground disposal vaults. In the authors' opinion, it will be extremely difficult to satisfy this requirement.

Criterion 10 CFR 61.51 (a)(2) states: "The disposal site design and operation must be compatible with the disposal site closure and stabilization plan and lead to disposal site closure that provides reasonable assurance that the performance objectives of Subpart C of this part will be met."

Discussion. The criterion is directly applicable to the aboveground vault disposal method. Since this alternative contains multiple individual disposal units associated with a facility, the operations and closure of individual disposal units must be compatible with the site closure and stabilization plan.

This point has been considered and discussed in relation to shallow land burial by Tucker (1983) and by the NRC staff (Siefken and others, 1982; Pangburn and Pennifill, 1982). No conflicts or differences in design philosophy should occur between shallow land burial or vault disposal. However, it is recommended that due consideration be given to the compatibility of the design, operation, and closure of individual units, as well as the overall site.

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Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(3) states: "The disposal site must be designed to complement and improve, where appropriate, the ability of the disposal site's natural characteristics to assure that the performance objectives of Subpart C of this part will be met."

Discussion. The criterion is directly applicable to any alternative disposal method. In fact, the primary reason for considering any engineered facility for LLW disposal is that it may complement and improve the ability of the disposal site to meet the performance objectives. The aboveground vault alternative may be considered an extreme example of this reasoning, because of its heavy reliance on design features to meet the performance objectives.

Recommendation. This criterion should be retained as is.

Criterion 10 CFR 61.51 (a)(4) states: "Covers must be designed to minimize to the extent practicable water infiltration, to direct percolating or surface water away from the disposed waste and to resist degradation by surface geologic processes and biotic activity."

Discussion. This requirement's objectives are valid. If "covers" are broadly defined to include vault roofs, then the criterion is judged to be applicable. If so defined, the vault roof should also resist degradation from climatological and meteorological processes, as well as surface geologic processes and biotic activity, as pointed out in the Task 1 report.

Recommendation. The criterion may be retained as is. However, the points raised in the above discussion should be considered in the application of the criterion to this alternative.

Criterion 10 CFR 61.51 (a)(5) states: "Surface features must direct surface water drainage away from disposal units at velocities and gradients which will not result in erosion that will require ongoing active maintenance in the future."

Discussion. The objective of this requirement is valid. Methods and features for enhancing surface drainage and minimizing erosion and resulting maintenance have been suggested in previous sections of this report. Tucker (1983) recommends surface grading practices to minimize this problem. He also provides guidance on susceptibility of various soils to erosion and recommends various surface ditch profiles and slopes for reducing erosion of these ditches. The primary methods for minimizing erosion are to limit the area over which runoff flows, provide gentle slopes, and channel the runoff into drainage ditches which may be sodded or covered by concrete or other materials to protect them.

Recommendation. The criterion should be retained as is.

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Criterion 10 CFR 61.51 (a)(6) states: "The disposal site must be designed to minimize to the extent practicable the contact of water with waste during storage, the contact of standing water with waste during disposal, and the contact of percolating or standing water with wastes after disposal."

Discussion. Again this requirement is valid and achievable. The risk of each of the potential causes of contact of water with wastes can be minimized. Temporary storage areas should be sloped and covered with roofs, or temporary storage times should be as short as possible. If drainage layers and gravity drainage are used, the contact of standing water with wastes during disposal should be minimal. Disposal operations should cease during rain and snow storms. If satisfactory materials and construction methods are used the contact of infiltrating water should be minimized.

Recommendation. The criterion should be retained as is.

3.2.3 Suggested Additional Technical Considerations

No specific supplemental criteria are thought to be necessary for aboveground vault disposal-site design. However, the design issues discussed in Part 2 should be considered because of the critical importance of design features in meeting the performance objectives with this method.

The surface release pathways assume increased importance for aboveground disposal and should be carefully analyzed.

3.3 Operations and Closure

3.3.1 Importance of Well Planned and Executed Operations and Closure Strategy

The main points to consider in planning for operations and closure of any LLW disposal facility are:

(1) Worker safety with respect to radiological hazards and hazards associated with excavation, construction, and maintenance of the site facilities.

(2) Compatibility of activities to minimize interference among construction, operations, monitoring, and temporary and final closure.

(3) Avoidance of activities that would lead to long-term active maintenance problems.

(4) Records management and quality control and assurance.

(5) Maintenance of a buffer zone of sufficient lateral and vertical extent that enough space and time would be available to carry out remedial actions should they be required. The remedial-action plan should be keyed to minimizing off-site releases of radionuclides

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during the period of significant hazard. Maintenance of an effective buffer zone around an aboveground vault may present a technical or economical challenge.

(6) Effective land use.

3.3.2 Assessment of Existing Criteria

The 11 existing criteria for evaluation of land disposal facility operation and disposal-site closure are listed under 10 CFR Part 61 Subpart D, paragraph 61.52.

As was done in the previous sections for site suitability and design, each criterion is listed, discussed, and a recommendation is then made to retain the criterion as is, modify the criterion, or not apply the criterion in the evaulation of this alternative. Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.52 (a)(1) states: "Wastes designated as Class A pursuant to paragraph 61.55, must be segregated from other wastes by placing in disposal units which are sufficiently separated from disposal units for the other waste classes so that any interaction between class A wastes and other wastes will not result in the failure to meet the performance objectives in Subpart C of this part. This segregation is not necessary for Class A wastes if they meet the stability requirements in paragraph 61.56(b) of this part."

Discussion. The rationale behind this requirement for land disposal is that mixing of structurally unstable class A wastes with Class B and Class C wastes could lead to differential settlement of the waste packages and the disposal-unit cover. Significant differential settlement would, in turn, lead to cracking of the cover and significant infiltration into the disposal unit.

However, an aboveground vault disposal unit is a stable, self-supporting unit that, by itself, satisfies the stability requirements of 61.56(b)(1). It does not have an earth cover and does not rely on structural support from the waste packages. Deterioration of waste packages would not result in settlement or increased infiltration into the disposal unit.

As mentioned in the introduction of this report, waste segregation was not considered as a prerequisite to disposal in engineered facilities. However, a potential problem that could result from decomposition of unstable Class A wastes should be considered. Products of decomposition of unstable Class A wastes could include gases and liquids which could damage the vault structure through chemical attack. This potential problem, together with economic considerations, are strong incentives for avoiding disposal of unstable Class A wastes in disposal vaults. If unstable wastes are disposed of in vaults, the wastes must be shown to pose no threat to the vault materials.

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Therefore, although segregation of unstable Class A wastes is judged to be unnecessary for avoidance of settlement and infiltration, other incentives exist to encourage segregation or stabilization, prior to disposal.

Recommendation. The criterion may be retained, although it is not directly applicable as written. For the reasons stated in the discussion above, segregation or stabilization of unstable Class A wastes is recommended.

Criterion 10 CFR 61.52 (a)(2) states: "Wastes designated as Class C pursuant to paragraph 61.55, must be disposed of so that the top of the waste is a minimum of 5 meters below the top surface of the cover or must be disposed of with intruder barriers that are designed to protect against an inadvertent intrusion for at least 500 years."

Discussion. Class C wastes represent the greatest long-term potential radiological hazard of any waste acceptable for near-surface disposal; primarily the hazard is to an inadvertent intruder. Consequently, these wastes should be isolated from the biosphere and the inadvertent intruder by a greater distance or barrier than other LLW. The requirement is valid and may be achieved through the use of concrete or other materials for construction of the vault. However, assurance of the long-term performance (without active maintenance) of man-made construction materials can only be based on extrapolation of short-term data, -- a less than ideal situation.

Recommendation. The criterion should be retained as is. It should be noted that the aboveground vault disposal method must satisfy the criterion through the use of an engineered intruder barrier.

Criterion 10 CFR 61.52 (a)(3) states: "All wastes shall be disposed of in accordance with the requirements of paragraphs (a)(4) through (11) of this section."

Discussion. The referenced requirements are discussed individually below.

Recommendation. This umbrella criterion may be retained without impact for any disposal method.

Criterion 10 CFR 61.52 (a)(4) states: "Wastes must be emplaced in a manner that maintains the package integrity during emplacement, minimizes the void spaces between packages, and permits the void spaces to be filled."

Discussion. Maintenance of package integrity is a valid objective for any alternative. Rupture of packages during operations would result in higher risks of radiation exposure to workers, and could result in contamination of equipment, areas adjacent to the disposal unit, and even off-site contamination if contaminated equipment leaves the site.

Minimization of voids promotes efficient use of disposal space. However, minimization of voids and filling of void spaces between waste packages in

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aboveground vault disposal units has no effect on minimization of subsidence. Radionuclide pathway analyses may indicate that migration is impeded by filling voids, and therefore the filling of voids may be desirable.

Recommendation. The criterion should be retained. Maintenance of package integrity is an important worker safety consideration. However, the objective of minimizing surface subsidence is not dependent on minimizing or filling voids.

Criterion 10 CFR 61.52 (a)(5) states: "Void spaces between waste packages must be filled with earth or other material to reduce future subsidence within the fill."

Discussion. See discussion of 61.52(a)(4) above.

Recommendation. The criterion may be retained. As stated above, however, the objective of minimizing subsidence is not dependent on filling of void spaces. Filling of void spaces may impede radionuclide migration and may therefore be encouraged. The potential benefits of filling voids inside vaults should be assessed for this reason.

Criterion 10 CFR 61.52 (a)(6) states: "Waste must be placed and covered in a manner that limits the radiation dose rate at the surface of the cover to levels that at a minimum will permit the licensee to comply with all provisions of paragraph 20.105 of this chapter at the time the license is transferred pursuant to paragraph 61.30 of this part."

Discussion. If covers are defined to include the vault roof as discussed under 61.51 (a)(4), then the criterion is judged to be applicable to aboveground vault disposal. Additionally, during the "operational" period of each unit, radiation dosages must also be limited at the surface, and additional shielding should be provided over high-activity wastes during the interim between placement and closure. It should be noted that the waste container and structural features of the disposal unit, e.g., the walls and roof, would enhance shielding and reduce surface doses.

Class C wastes and wastes with high surface radiation should be placed on the bottom and center of the disposal unit. Other wastes with lower surface radiation should be placed above and around the sides to reduce surface dose rates.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(7) states: "The boundaries and locations of each disposal unit (e.g., trenches) must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries of each unit can be easily defined. Three permanent survey marker control points, referenced to United States Geological Survey (USGS) or National Geodetic Survey (NGS) survey control stations, must be

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established on the site to facilitate surveys. The USGS or NGS control stations must provide horizontal and vertical controls as checked against USGS or NGS record files."

Discussion. This requirement is necessary for belowground disposal methods. However, aboveground vaults may be located and their boundaries ascertained without benefit of surveys or survey markers or maps. Even so, practical considerations of site layout for efficient land use would almost certainly lead to the use of boundary surveys, topographic surveys, disposal-unit surveys, and related mapping.

Recommendation. The criterion may be retained but the requirements may be too prescriptive for this method. Boundary and disposal-unit surveys are certain to be used but are not required for the stated objective of locating the disposal unit even after the institutional control period has ended because the vaults are visible.

Criterion 10 CFR 61.52 (a)(8) states: "A buffer zone of land must be maintained between any buried waste and the disposal site boundary and beneath the disposed waste. The buffer zone shall be of adequate dimensions to carry out environmental monitoring activities specified in 10 CFR 61.53(d) of this part and take mitigative meamsures if needed."

Discussion. This requirement was specified to ensure that adequate space and time would be available to detect and correct any performance deficiencies before the deficiencies manifest themselves at the site boundary. The requirement for sufficient space can be satisfied with aboveground vaults by providing space between units or rows of units. However, the time required to take mitigation measures is the critical issue with aboveground vaults because of the lack of a soil cover. As discussed previously, the vault envelope is the only barrier to radionuclide migration through the atmosphere. The soil below the vault foundation may be expected to perform as it does for belowground disposal to retard radionuclide migration through the subsurface and ground-water pathways. Likewise, backfill placed around the waste packages in the vault would serve as an additional barrier. However, if the monitoring system is designed to detect migration only at the vault surface, then insufficient time may be available to take mitigative measures before unacceptable releases of radionuclides occur. On the other hand, monitoring the inside of the vault would be difficult to accomplish without compromising the integrity of the vault and may not provide data from which reasonable predictions of long-term performance can be made. This problem is considered to be an important issue and one for which no completely satisfactory solution may be found. One possible vault monitoring method was shown in Figure 1, but it is not entirely satisfactory as it may compromise the integrity of the vault or lead to long-term active maintenance problems.

Recommendation. The objective of this criterion is valid and the criterion should be retained as is. However, in the authors' opinion, it will be difficult to demonstrate that sufficient time will be available for taking mitigative measures using aboveground disposal vaults.

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Criterion 10 CFR 61.52 (a)(9) states: "Closure and stabilization measures as set forth in the approved site closure plan must be carried out as each disposal unit (e.g., each trench) is filled and covered."

Discussion. As discussed by Pangburn and Pennifill (1982), the purpose of this requirement is primarily to minimize the number and extent of activities to be performed at the time of site closure. By closing and stabilizing disposal units as they are completed, the operator will be able to focus on final closure and stabilization. Moreover, early closure and stabilization will help to minimize infiltration, lower dose rates to site personnel, and protect waste-package integrity. Early closure of filled disposal units also provides valuable experience from which to fine-tune final closure methods. Finally, if completed disposal units are not promptly closed and stabilized, the probability of achieving long-term isolation and avoidance of the need for continuing active maintenance could be compromised. Therefore, an applicant should provide, as part of the application, a closure and stabilization plan to be implemented upon completion of any given disposal unit. To assure closures within a reasonable time period a construction sequencing plan with projected future waste quantities and categories should be submitted to indicate facility operation and closure time periods.

Disposal units that have been closed should be periodically inspected to ensure satisfactory performance. Such inspections should identify areas of foundation or surface erosion, structural conditions including cracking and settlement, ponding and condition and extent of vegetation.

Problems noted should be accompanied by plans for remedial action. Subsequent inspections should note whether such remedial actions were undertaken and whether the noted problem has been corrected or still exists. Procedures similar to these have been followed for decades by the Corps of Engineers in their periodic inspections and evaluations of locks and dams and other civil works.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.52 (a)(10) states: "Active waste disposal operations must not have an adverse effect on completed closure and stabilization measures."

Discussion. This requirement seeks to ensure that active operations do not result in damage to completed disposal units. Satisfaction of this requirement is achievable through planning of both normal operations and contingencies. Simple examples would include allowing enough room between disposal units for normal equipment movements and temporary storage of excavated materials, such that adjacent units and monitoring points are not endangered.

Sufficient room should be provided between arrays of disposal units to allow for surface water management features and closure of completed units.

Recommendation. The criterion should be retained as is.

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Criterion 10 CFR 61.52 (a)(11) states: "Only wastes containing or contaminated with radioactive materials shall be disposed of at the disposal site."

Discussion. This criterion is directly applicable to the aboveground vault disposal alternative. However, it may not go far enough in stating what may not be disposed of, e.g., hazardous or toxic wastes that are slightly radioactive. This issue is considered within the criteria for waste characteristics, paragraph 61.56. However, the intent of paragraph 61.56 is to facilitate handling to ensure protection of the health and safety of workers, and to protect the environment from incidental concentrations of hazardous material. In addition, the potential for damage to the vault from the contained wastes, e.g., chemical attack should be considered.

Recommendation. The criterion should be retained as is but the additional concern discussed above should be addressed.

3.3.3 Suggested Additional Technical Considerations

In addition to the comments and suggestions made in the discussion of each existing criterion, it is recommended that the potential benefits of filling voids inside vaults be assessed, as well as the potential for increased worker exposures.

3.4 Monitoring

3.4.1 Objectives of Monitoring

The overall objective of monitoring any low-level radioactive waste disposal facility is to provide reasonable assurance that the performance objectives are being met. Monitoring is considered to include the systematic collection, analysis, and interpretation of data related to the radiological, chemical, physical, and environmental properties of specific media in the vicinity of a LLW site during all phases of site life. In addition, structural performance should be monitored.

In addition to determining compliance with the performance objectives established in 10 CFR Part 61, the monitoring program should also:

a. Aid in site characterization.

b. Establish a statistical data-base for background values of parameters of concern.

c. Provide a data-base useful in the selection and verification of a site model.

d. Provide a method for determining when corrective actions are necessary, i.e., a plan of action to be implemented when the values of one or more critical parameters exceed a specified action level.

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The monitoring program extends from the preoperational site-investigation program through the operation period, and for some time after closure.

Lutton and others (1982a, 1982b, and 1983) in a series of three reports (NUREG/CR-2700, NUREG/CR-3038, and NUREG/CR-3164) described the parameters which should be monitored, test methods and equipment required to measure these parameter values, and a comprehensive subsurface monitoring program that could achieve the intended objectives at LLW disposal sites. Sedlett and others (1982) have also developed a handbook for environmental monitoring of LLW disposal sites. Rogers, Sutherland, and Adam (1982) have developed a handbook for LLW disposal that discusses specific objectives and gives examples of monitoring techniques suitable for shallow land burial. Most of these recommendations would be equally applicable to an aboveground vault disposal facility.

It is not the purpose of this report to make recommendations concerning a specific program for monitoring disposal facilities. Such a program must be site-specific and based on the design and plans for operation and closure of the facility. The above references, NRC staff position papers, and the existing monitoring criteria, along with the recommendations in this report, should provide adequate basis for development of specific monitoring programs.

It should be emphasized that, if the disposal facility is properly sited, designed, and operated, the major function of the monitoring program is to provide reassurance of satisfactory performance and safety of the facility.

3.4.2 Assessment of Existing Criteria

The existing criteria for environmental monitoring of land disposal of LLW are contained in paragraph 61.53 of 10 CFR Part 61 Subpart D. These four criteria are listed in subparagraphs 61.53 (a)-(d) and are listed and discussed individually below. Additional technical considerations are discussed at the end of this section.

Criterion 10 CFR 61.53 (a) states: "At the time a license application is submitted, the applicant shall have conducted a preoperational monitoring program to provide basic environmental data on the disposal site characteristics. The applicant shall obtain information about the ecology, meteorology, climate, hydrology, geology, geochemistry, and seismology of the disposal site. For those characteristics that are subject to seasonal variation, data must cover at least a 12-month period."

Discussion. The requirement is basic to the establishment of site suitability, design-basis natural events, and operations and closure plans. While the specific information that is to be collected and its relative importance can be expected to vary, as well as the use to which it is put, the need for a systematic program is absolute.

Recommendation. The criterion should be retained as is.

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Criterion 10 CFR 61.53 (b) states: " The licensee must have plans for taking corrective measures if migration of radionuclides would indicate that the performance objectives of Subpart C may not be met."

Discussion. This requirement is valid and suggests the need for further requirement that the licensee have on file plans for specific actions if detected concentrations or rates of migration of radionuclides exceed pre-established limits. The action plan should indicate methods and equipment to be used and the time table for mobilization. This requirement is considered to be a critical element for aboveground vault disposal because of the lack of a geological barrier. Reaction to the release and implementation of the planned action may be effected before radionuclides migrate beyond the site boundary.

Recommendation. The criterion should be retained as is.

Criterion 10 CFR 61.53 (c) states: "During the land disposal facility site construction and operation, the licensee shall maintain a monitoring program. Measurements and observations must be made and recorded to provide data to evaluate the potential health and environmental impacts during both the construction and the operation of the facility and to enable the evaluation of long-term effects and the need for mitigative measures. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. The criterion is valid. It is recommended, however, that at the time of license application and review, specific reporting requirements be included. The reporting requirements should be keyed to the specific sample data and frequency of measurements of those data that would be required by analyses to demonstrate satisfactory performance.

In addition, a plan should be submitted for disposal of surface drainage water and ground water that has been sampled, tested, and found to contain significant radionuclide concentrations. As discussed under the previous criterion, plans for mitigative measures should also be submitted for approval, prior to operation.

As pointed out in the discussion of 61.52 (a)(8), the requirement that the monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary will be difficult to satisfy with aboveground vaults.

Recommendation. The criterion should be retained. However, it should be expanded to include the above requirements. Alternatively, these requirements should be addressed by supplemental criteria.

Criterion 10 CFR 61.53 (d) states: "After the disposal site is closed, the licensee responsible for postoperational surveillance of the disposal site shall maintain a monitoring system based on the operating history and the

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closure and stabilization of the disposal site. The monitoring system must be capable of providing early warning of releases of radionuclides from the disposal site before they leave the site boundary."

Discussion. This requirement is valid. However, referring again to the previous discussion of 61.52 (a)(8) and 61.53 (c), this requirement will be difficult to satisfy.

Recommendation. The criterion should be retained as is.

3.4.3 Suggested Additional Technical Considerations

Other than the considerations discussed under the respective existing criteria, it is recommended that each disposal unit be monitored individually for structural and radiological safety so that any problems that develop can be quickly traced to their origins and corrected.

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4. CONCLUSIONS AND RECOMMENDATIONS

An aboveground vault facility for disposal of LLW is not a near-surface disposal facility as strictly defined in 10 CFR Part 61.2. However, the method would be similar in some respects to current practices for near-surface disposal. It is amenable to evaluation using the existing technical criteria specified in 10 CFR Part 61 Subpart D. Exceptions have been discussed in Part 3 and are summarized here.

In the assessment of site suitability criteria, the possible exception for allowing disposal below the water table in criterion 61.50 (a)(7) obviously cannot be applied to aboveground vaults. The wording of 61.50 (a)(8) referring to "the hydrogeologic unit used for disposal" is not appropriate since an aboveground vault is not a hydrogeologic unit.

In the assessment of design criteria, the goal stated in 61.51 (a)(1) of avoidance of the need for continuing active maintenance after site closure will be a critical test of the feasibility of aboveground vault disposal. The goal of the criterion is valid, but will be difficult to satisfy with this method. In the application of 61.51 (a)(4), the term "covers" must be defined to include vault roofs if the criterion is to be applied to this method.

Operation and closure criterion 61.52 (a)(1), which requires segregation of unstable Class A wastes prior to disposal, is not directly applicable to aboveground vaults. An aboveground vault is a stable, self-supporting structure that by itself satisfies the stability requirements of 61.56 (b)(1). It does not rely on structural support from the waste packages. Deterioration of waste packages would not result in settlement or increased infiltration, and thus segregation or stabilization are not required to meet the objectives of the requirement. However, the potential for damage to the vault structure that could result from products of decomposition attacking construction materials should be assessed. The unstable wastes must be shown to pose no threat to the integrity of vault construction materials. This potential problem, together with economic considerations, are strong incentives to segregate or stabilize these wastes prior to disposal.

It will be difficult to demonstrate satisfaction of the requirement stated in 61.52 (a)(2) for an intruder barrier consisting of man-made materials with an effective life of 500 years, without long-term active maintenance. However, the high visibility of the aboveground disposal vault is a deterrent to inadvertent intrusion.

The requirements stated in 61.52 (a)(4) for minimization of void spaces and in 61.52 (a)(5) for filling of void spaces are not necessary to achieve the goals of these criteria, i.e., to minimize subsidence. As stated previously, the aboveground vault is self-supporting and does not rely on minimization of voids or filling of voids to minimize subsidence. However, radionuclide pathway analyses may indicate that migration is impeded by filling voids, in which case void filling would be recommended. Therefore, the potential benefits of void filling should be assessed.

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Criterion 61.52 (a)(7) has a valid objective, i.e., to ensure positive location of disposal units in case remedial actions become necessary and to prevent inadvertent intrusion. It is almost certain that boundary surveys and disposal-unit surveys will be performed for efficient land use. However, surveying and marking the boundaries of the vaults is not required for positive location. Vault boundaries can be visually ascertained.

The requirement of a buffer zone stated in 61.52 (a)(8) of adequate dimensions to carry out environmental monitoring and take mitigative measures if needed can be satisfied. However, the time available to take mitigative measures before radionuclides migrate off site is the critical issue because the vault envelope is the only barrier to atmospheric migration. Thus, satisfaction of the requirement will be difficult with aboveground vaults.

In the assessment of 61.52 (a)(11), the potential for damage to the vault from the contained waste, e.g. by chemical attack, should be considered.

All of the monitoring criteria are applicable to aboveground vault disposal. However, as mentioned previously, the requirements in 61.53 (c) and (d) that the monitoring system be capable of providing early warning of releases of radionuclides before they reach the site boundary will be difficult to achieve in practice, given the lack of a buffer zone around the vault envelope.

In addition to the problems related to satisfaction of the existing criteria which must be resolved as discussed above, additional technical issues are recommended for consideration. These include, for determination of site suitability, the need to assess the occurrence and impacts of dispersive soils, liquefiable soils, corrosive soils, expansive soils, karstic or cavernous areas, and areas undergoing subsidence. No additional technical issues must be addressed in the evaluation of aboveground vault design. However, the almost total reliance of this method on design features, as opposed to the site's natural characteristics, in meeting the performance objectives is emphasized. Other than the issues discussed in the assessment of existing criteria, additional technical issues that should be addressed in the evaluation of aboveground vault operations and closure are the potential benefits of filling voids inside the vault and potential for increased worker exposures. It is recommended that each disposal unit should be monitored for structural and radiological safety during the operations period.

Only a limited amount of short-term experience has been gained with the storage of LLW in aboveground vaults. No long-term disposal experience is available from which the performance capabilities of this method may be reliably inferred. Aboveground vaults have been used extensively to warehouse raw and finished goods, but these applications do not require long-term performance without active maintenance or repair.

This lack of experience, together with the inherent difficulties of satisfying some of the technical requirements noted herein, raises serious questions about the ability of aboveground disposal to meet the long-term performance

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objectives specified in 10 CFR Part 61 Subpart C or the related technical requirements of Subpart D. A license applicant who proposes an aboveground disposal facility will be faced with a difficult case to provide satisfactory assurances to the licensing authorities that the facility can meet the performance objectives.

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GLOSSARY

ACTIVE MAINTENANCE: Any significant remedial activity needed during the period of institutional control to maintain a reasonable assurance that the performance objectives in 10 CFR 61.41 and 61.42 are met. Such active maintenance includes ongoing activities such as the pumping and treatment of water from a disposal unit or one-time measures such as replacement of a disposal unit cover. Active maintenance does not include custodial activities such as repair of fencing, repair or replacement of monitoring equipment, revegetation, minor additions to soil cover, minor repair of disposal unit covers, and general disposal site upkeep such as mowing grass.

ACTIVITY: A measure of the rate at which a material is emitting nuclear radiations; usually given in terms of a the number of nuclear disintegrations occurring in a given quantity of material over a unit of time; the standard unit of activity is the curie (Ci), which is equal to 3.7×10^{10} disintegrations per second.

AGREEMENT STATES: Any States with which the Commission or the AEC has entered into an effective agreement under subsection 274b of the Atomic Energy Act of 1954. A Nonagreement State is any other State. (10 CFR 150.3)

AQUICLUDE: A formation which, although porous and capable of absorbing water, does not transmit it at rates sufficient to furnish an appreciable supply for a well or spring. (ASTM STP 746)

AQUIFER: Geologic stratum or set of beds with relatively high transmissivity and carrying ground water in quantities to make exploitation for consumption economically feasible.

BACKGROUND RADIATION: Radiation in the environment from naturally occurring radioactive elements, cosmic radiation, and fallout from man's activities such as nuclear weapons testing.

BUFFER ZONE: A portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site.

CURIE (Ci): A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7×10^{10} disintegrations per second (d/s); millicurie (mCi) = 10^{-3} curie; microcurie (Ci) = 10^{-6} curie; nanocurie (nCi) = 10^{-9} curie; picocurie (pCi) = 10^{-12} curie; femtocurie (fCi) = 10^{-15} curie.

DECONTAMINATION: The selective removal of radioactive material from a surface or from within another material.

DISPOSAL SITE: That portion of a land disposal facility which is used for disposal of waste. It consists of disposal units and a buffer zone.

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DISPOSAL UNIT: A discrete portion of the disposal site into which waste is placed for disposal. For current near-surface disposal the unit is usually a trench.

ENGINEERED BARRIER: A man-made structure or device that is intended to improve a land disposal facility's ability to meet the performance objectives in 10 CFR Part 61, Subpart C.

ENGINEERED DISPOSAL: As used in this report, the disposal of radioactive wastes, usually in suitable sealed containers, in any of a variety of structures especially designed to protect them from water and weather and to prevent leakage to the biosphere by accident or sabotage.

ENVIRONMENTAL SURVEILLANCE: Monitoring of the impact on the surrounding region of the discharges from industrial operations, forest fires, storm runoff, or other natural or man-induced events.

EXPOSURE: A measure of the ionization produced in air by X or gamma radiation. It is the quotient of (1) the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by (2) the mass of the air in the volume element. The special unit of exposure is the Roentgen. (Radiological Health Handbook, U.S. Dept. of HEW). Acute exposure generally refers to a high level of exposure of short duration; chronic exposure is lower-level exposure of long duration.

GROUND WATER: Water that exists or flows below the ground surface (within the zone of saturation).

GROUT: Fluid or semifluid material, often containing Portland cement, which may be pumped or poured into earth strata and by setting up into solid state, provides mechanical stabilization or water flow control.

HALF-LIFE: The time in which half the atoms of a particular radioactive substance disintegrate to another nuclear form. Measured half-lives vary from millionths of a second to billions of years. After a period of time equal to 10 half-lives, the radioactivity of a radionuclide has decreased to 0.1 percent of its original level.

HAZARDOUS WASTE: Those wastes designated as hazardous by Environmental Protection Agency regulations in 40 CFR Part 261.

HYDROGEOLOGY: The study of ground water, with particular emphasis on its chemistry, mode of migration, and relation to the geologic environment. (Davis and De Wiest, 1966).

HYDROGEOLOGIC UNIT: Any soil or rock unit or zone which by virtue of its porosity or permeability, or lack thereof, has a distinct influence on the storage or movement of ground water.

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IN SITU: In the natural or original position; used to refer to in-place experiments at a storage or disposal site.

INADVERTENT INTRUDER: A person who might occupy a disposal site after closure and engage in normal activities, such as agriculture, dwelling construction, or other pursuits, in which the person might be unknowingly exposed to radiation from the waste.

INTRUDER BARRIER: A sufficient containment of the waste that inhibits human contact with waste and helps to ensure that radiation exposures to an inadvertent intruder will meet the performance objectives set forth in 10 CFR 61; or engineered structures that provide equivalent protection to the inadvertent intruder.

ION: Atomic particle, atom, or chemical radical bearing an electrical charge, either negative or positive.

ION EXCHANGE: A reversible interchange that takes place between ions of like charge, usually between ions present on an insoluble solid and ions in a solution surrounding the solid. An important process in both fundamental and industrial chemistry.

ION-EXCHANGE RESIN: An insoluble polymerized electrolyte that contains either acidic groups for exchanging cations or basic groups for exchanging anions. It contains large, high-molecular-weight ions of one charge and small, simple ions of the opposite charge. The small ions undergo exchange with ions in solution.

IONIZING RADIATION: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

ISOTOPES: Nuclides having the same number of protons in their nuclei, and hence the same atomic number, but differing in the number of neutrons and therefore, in the mass number. Identical chemical properties exist between isotopes of a particular element.

KARST: Surface or subsurface rock mass conditions characterized by solution-formed caverns, cavities, open joints, pinnacles, and depressions of a highly irregular form. Almost exclusively applied to carbonate lithologies, e.g., limestone.

LAND DISPOSAL FACILITY: Land, buildings, and equipment intended to be used for the disposal of radioactive wastes into the subsurface of the land. A geologic repository as defined in 10 CFR 60 is not considered a land disposal facility. (10 CFR 61.2)

LEACHING: The process of extracting a soluble component from a solid by the percolation of a solvent (e.g., water) through the solid.

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LIQUEFIABLE: Susceptible to near-total loss of shear strength and bearing capacity during seismic disturbances; used with reference to soils.

LITHOLOGY: The character of a rock formation or of the rock found in a geological area or stratum expressed in terms of its structure, mineral composition, color, and texture.

LOW-LEVEL RADIOACTIVE WASTE (LLW): Radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or by-product material as defined in section 11e(2) of the Atomic Energy Act of 1954. (P.L. 96-573) Radioactive wastes containing source, special nuclear, or by-product material that are acceptable for disposal in a land disposal facility (10 CFR 61/2). For explanation of Class A, Class B, and Class C LLW, see 10 CFR 61.55 and 61.56.

NEAR-SURFACE DISPOSAL FACILITY: A land disposal facility in which radioactive waste is disposed of in or within the upper 30 meters of the earth's surface.

PERMEABILITY: The capacity of a porous medium to conduct liquids or gases.

PIEZOMETER: An instrument for measuring pressure head in ground water. In an unconfined aquifer with a free water table, a piezometer is frequently an open-bottomed monitor well extending below that water table.

PSYCHROMETER: Device used for measuring the amount of water vapor in air; e.g., a hydrometer.

PYROPHORIC: Igniting spontaneously. A pyrophoric liquid is any liquid that ignites spontaneously in dry or moist air at or below 130 degrees F (54.5 degrees C). A pyrophoric solid is any solid material, other than one classed as an explosive, which under normal conditions is liable to cause fires through friction, retained heat from manufacturing or processing, or which can be ignited readily and when ignited burns so vigorously and persistently as to create a serious transportation, handling, or disposal hazard. Included are spontaneously combustible and water-reactive materials.

RAD: The unit of absorbed dose equal to 100 ergs per gram or 0.01 joule per kilogram.

RADIOACTIVITY: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emmitting X radiation following orbital electron capture, or of undergoing spontaneous fission. (Radiological Health Handbook, U.S. Dept. of HEW)

REM: A special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, the distribution factor, and any other necessary modifying factors. (Radiological Health Handbook, U.S. Dept. of HEW) The dosage of any ionizing radiation that will cause the same amount of biological injury to human tissue

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as one roentgen of X-ray or gamma-ray dosage. (Webster's Third New International Dictionary) (1 millirem = 0.001 REM)

REPOSITORY: A term generally applied to a facility for the disposal of radioactive wastes, particularly high-level waste and spent fuel.

ROENTGEN: The special unit of exposure. One roentgen equals 2.58×10^{-4} coulomb per kilogram of air. (Radiological Health Handbook, U.S. Dept. of HEW) The international unit of X radiation or gamma radiation that is the amount of radiation producing, under ideal conditions in one cubic centimeter of air at 0 degrees C and 760 mm Hg pressure, ionization of either sign equal to one electrostatic unit of charge. (Webster's Third New International Dictionary)

SEISMIC: Of, pertaining to, of the nature of, subject to, or caused by an earthquake.

SITE CLOSURE AND STABILIZATION: Those actions that are taken upon completion of operations that prepare the disposal site for custodial care and that assure that the disposal site will remain stable and will not need ongoing active maintenance.

SUBSIDENCE: Sinking or depression of the ground surface; generally due to loss of subsurface support.

SURVEILLANCE: Observation of the disposal site for purposes of visual detection of need for maintenance, custodial care, evidence of intrusion, and compliance with other license and regulatory requirements.

TECTONIC: Of or relating to the deformation of the earth's crust, the forces involved in or producing such deformation, and the resulting rock structures and external forms.

TRANSMISSIVITY: A property of an aquifer; the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the water aquifer under a unit hydraulic gradient.

TRANSURANIC (TRU) WASTE: Waste that, without regard to source or form, at the end of institutional control periods is contaminated with alpha-emitting radionuclides of atomic number greater than 92 and half-lives greater than 20 years in concentrations greater than 100 nanocuries per gram (nCi/g), or has a smearable alpha contamination greater than 400 dpm/cm^2 averaged over the accessible surface.

UNSATURATED ZONE: The zone of soil or rock between the ground surface and the water table; also termed the vadose zone.

VAULT: An enclosed space covered by an overhead structure; especially a passage or room used for storage or safekeeping.

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VULCANISM: The process by which magma (molten rock material within the earth) and its associated gases rise into the earth's crust and are extruded onto the earth's surface and into the atmosphere.

WATER TABLE: The surface within an unconfined aquifer between the zone of saturation and the zone of aeration; that surface of a body of unconfined ground water at which the pressure is equal to atmospheric pressure.

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APPENDIX A

Long Term Performance and Durability of Portland Cement Concrete as the Building Material for Engineered Facilities

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CTD/SL

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1. Introduction

The disposal of low-level radioactive waste in engineered facilities requires an in-depth evaluation of the construction materials used to attempt the prediction of the service life of structures used for this disposal. This section of the report addresses the parameters to be considered in the use of reinforced portland-cement concrete as the building material for disposal vault or other engineered facilities.

Predicting behavior and durability of materials and structures for long periods of time, such as 500 years, has, as its foundation, extrapolation of short-term data, which in many cases may lack a proper rationale. The ancient Roman engineers and builders produced constructions that we can examine today but passed on very little written narrative of how they designed and constructed their projects (Malinowski, 1979). Present-day efforts to reconstruct, by deduction, the formulation of concrete mixtures, the identification of the exact materials, and a definite statement as to construction methodology have met with only slight success (Malinowski, 1979 and Roy and Langton, 1983). However, these studies permit better understanding of the aging process that may be expected for certain materials.

Predicting the long-term stability and performance of materials such as cements, mortars, and concrete may be approached in two ways: (1) examination of the physical performance of old structures and (2) interpretation of the chemical activity of the observed durability of old cementing materials.

Long-term performance is an approximate synonym of durability, and the factors which impair such durability will determine its long-term performance.

Generally, concrete durability depends on its porosity, permeability, absorptivity, capillarity, response to imposed stresses, and bond of the components.

2. Factors that Impair the Integrity of Concrete

The structural integrity of a reinforced portland-cement concrete structure is a function of the quality and durability of the structure in response to the applied loads and stresses and of the durability and quality of the concrete contained in the structure. Durability of a structure has been defined (ASTM, 1977) as "the safe performance of a structure or a portion of a structure for the designed life expectancy." Durability of portland cement concrete has been defined (ACI, 1977) as "its ability to resist weathering action, chemical attack, abrasion, or any other process of deterioration." It is essential to recognize the main types of concrete deterioration and then address measures and techniques that can be employed to protect against these attacks.

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American Concrete Institute (ACI) Committee 201 (ACI, 1977) has listed five important causes of concrete deterioration as: (1) freezing and thawing, (2) aggressive chemical exposure, (3) abrasion, (4) corrosion of steel and other metals embedded in concrete, and (5) chemical reactions of aggregates. The following paragraphs define and discuss these causes.

2.1 Freezing and Thawing

Freezing and thawing damage is the phenomenon that occurs when critically saturated concrete is subjected to freezing and thawing. Hardened cement paste and aggregate have very different behavior responses to freezing and thawing and therefore should be considered separately.

2.1.1 Freezing and thawing of cement paste. The porosity of cement paste, in fairly dense and well consolidated concrete, is between 30 percent and 50 percent. This pore structure becomes reservoirs for water which can freeze and cause disruptive and damaging action. The research done by Powers (1945, 1954, 1955), Helmuth (1960), Collins (1944), and Litvan (1974) produced what is generally accepted as the mechanisms taking place during freezing, though each researcher's findings differ somewhat in detail. It is now believed by many researchers that osmotic pressure of the freezing water in the pores and connecting capillaries causes most of the frost damage in cement paste (ASTM, 1977). The pressures generated by this mechanism cause the paste to fail, which in turn, causes the concrete mass to fail.

Generally, it is agreed (and has been demonstrated time and again) that air entrainment of cement paste can produce a paste that will not be affected by freezing and thawing provided sufficient hydration of cement has taken place before the paste is allowed to freeze while critically saturated. Air entrainment produces a pore distribution system, with appropriate distances between pores, which will accommodate ice movement and pressures.

2.1.2 Freezing and thawing of aggregate particles. As just stated, air entrainment can prevent damage in cement paste, but the freezing action in aggregate particles must also be considered so as to produce a concrete that will be free of damage.

The basic mechanism is called "the hydraulic pressure theory (ASTM, 1977)." Powers (1945) found that the pores of rocks, which are often larger than paste pores, if water filled, expel water during freezing and thereby produce a hydraulic pressure which can cause failure.

In addition, Verbeck and Landgren (1960) found that in coarse aggregate from any given natural rock, there is a critical size below which, if unconfined by cement paste, the material can be frozen without damage.

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The overall effect on a concrete composed of sound aggregate and paste of appropriate maturity which has an appropriate air-entrained void system characterized by a spacing factor (maximum distance from any point in the paste to the periphery of a nearby air void) of less than 0.008 in. is one in which no destructive stresses are produced during freezing.

2.2 Aggressive Chemical Exposure

Concrete of good quality will perform satisfactorily when exposed to many chemicals. There are, however, some chemical environments under which the useful life of concrete will be short.

Table 1 lists certain chemicals which attack concrete and recommendations for preventative or remedial protection (Highway Research Board of the National Academy of Sciences, 1966).

Chemical attack on concrete is generally the result of exposure to sulfates or acids, and these are discussed below.

Sulfate attack is a particular problem in arid areas, such as the northern Great Plains area and parts of the western United States. Sulfates such as those found in soils and groundwaters near concrete structures can attack concrete. In the presence of moisture, an expansive reaction takes place between the tricalcium aluminate (C_3A) phase of portland cement and sulfates to produce calcium sulphoaluminate which will cause disruption of concretes. If the C_3A content is lowered during burning of the cement clinker by converting it to tetracalcium alluminoferrite (C_4AF), which is not so suceptible, this produces an effective means of combating sulfate attack.

Type V cement which may not contain more than 5 percent by weight of C_3A, has been found to perform satisfactorily in severe sulfate exposures. Type II cement may not contain more than 8 percent by weight of C_3A and provides moderate sulfate resistance.

In general, portland cement is not acid resistant, but it can withstand weak acids (pH greater than 4.0). Water draining from mines or landfills, some industrial water, and falling rain may contain or form acids which attack concrete. Also, sulfuric acid, carbonic acid, and sulfates are common in ground-water, which could cause corrosion of embedded steel and sulfate attack in concrete.

Acid attack, with the attendent resulting deterioration, is characterized by a chemical reaction between the acid and the calcium hydroxide of the hydrated portland cement. This results in the formation of water-soluble calcium compounds. These in turn are leached away. This total mechanism destroys the binding ability of the cement paste.

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Table 1

Certain Chemicals Harmful to Concrete (Effects and Remedies)

Substance	Effect	Remedy
Acetic acid	Causes slow disintegration	Use heavy duty floors with bituminous or polysulfide coatings
Calcium sulfate	Because of limited solubility, attack is less than other sulfates	Use epoxy, rubber, or bituminous coatings: use high quality concrete with high cement factor and air entrainment
Carbon dioxide	No damage to mature concrete, but can dissolve in water to form carbonic acid	Use surface hardeners and coatings: properly vent combustion heaters when placing concrete in heated enclosure
Carbonic acid	Very corrosive to lean mixtures; slowly disintegrates better quality concrete	Use dense, impermeable concrete with high cement factor: use epoxy, neoprene, or vinyl coatings
Fats and oils	Attack varies, depending on concentration of fatty acids and viscosity of oils	Use low water-cement ratio; dense, impermeable concrete; use surface hardeners (Magnesium or zinc flurosilicate), oil-insoluble resin
Hydrobromic acid, hydrochloric acid	Constant contact by strong solution destroys concrete; weak solutions attack slowly	Use protective coatings per ACI 515
Hydrogen sulfide	Sulfuric acid is produced in moist, oxidizing environments, which causes slow disintegration	Use concrete of low permeability; use coatings of polyester, neoprene or epoxy
Iron sulfide	Slow disintegration of low quality concrete if substance contains ferric sulfate	Use good quality concrete; use epoxy, chlorosulfonated polyethylene, or polyester coatings

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Table 1 (Continued)

Substance	Effect	Remedy
Magnesium sulfate	0.5% solution (or more) aggressively attacks concrete with low sulfate resistance, causes disruptive expansion	Use high quality air-entrained concrete with high cement factor; use epoxy, rubber, or bituminous coatings
Nitric acid	Constant contact of strong solution destroys concrete	Use protective coatings per ACI 515
Sodium carbonate in solution	Does not affect mature concrete but causes fresh concrete to deteriorate	Protect fresh concrete from contamination
Sodium chloride	Corrodes reinforcing steel which can damage concrete member	Avoid use or presence of substance
Sodium sulfate	0.5% solutions (and greater) strongly attacks concrete of inadequate sulfate resistance	Use high quality air-entrained concrete with high cement factor; use bituminous, rubber, or epoxy coatings
Sulfur dioxide	Dry gas combined with moisture from acids cause long-term deterioration	Use vinyl, epoxy, or chlorinated rubber coatings
Sulfuric and sulfurous acids	Constant contact with strong solutions destroys concrete	Use protective coatings per ACI 515

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2.3 Abrasion

Abrasion is the wearing away of a concrete surface by rubbing and friction (ACI, 1967). To consider several mechanisms of abrasion, Prior (1966) has recommended four classifications of abrasion:

(1) Wear on concrete floors (foot traffic, light trucking, skidding, scraping, or sliding of objects on the surface).

(2) Wear on concrete roadways (automobiles with studded tires or chains, heavy trucks).

(3) Erosion in hydraulic structures (waterborne abrasive materials).

(4) Wear on water-carrying systems composed of concrete (high velocities and negative pressures).

Abrasion is a physical wearing away or breaking off of material on the surface of the concrete by the abrading agent. The factors, therefore, which affect the abrasion resistance of concrete to a given abrading agent are: compressive strength, aggregate properties, finishing methods, use of toppings or coatings, and curing. Therefore, higher compressive strength results in greater abrasion resistance; harder coarse and fine aggregate results in higher resistance; properly timing the finishing operations and producing a smooth, dense surface gives higher resistance; application of metallic or nonmetallic coatings to toughen the surface gives higher resistance; and, use of proper curing agents for the required time gives a higher resistance.

2.4 Reactive Aggregates

No aggregates should be considered completely chemically inert. Some of the chemical reactions can be beneficial but others can cause disruptive damage such as abnormal expansion, cracking, and loss of strength (Woods, 1968).

The most predominant harmful reaction is "alkali-silica reaction" and is defined as the reaction between hydroxyl ions associated with the dissolution of the cement alkalies (Na_2O and K_2O) and certain siliceous constituents that may be present in aggregates. This disruption is characterized by expansion and severe cracking of the concrete structure.

Another form of reaction is that between the hydroxyl ions associated with dissolution of the cement alkalies and certain carbonate rocks, usually argillaceous dolomitic limestones. The disruptive damage is usually characterized by expansion, cracking, and aggregate degradation.

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Other types of chemical reaction include oxidation or hydration of certain unstable mineral oxides, sulfates, or sulfides that occur after the aggregate has been incorporated into the concrete (Highway Research Board of the National Academy of Sciences, 1966).

All of these reactions usually result in such disruptive damage that the deteriorated concrete must be removed and replaced by sound concrete of better quality.

Table 2 is a summary of the deleterious aggregates discussed herein, derived from ASTM (1977).

2.5 Corrosion of Embedded Material

For corrosion of steel embedded in concrete to occur, the following conditions must all be met: (1) the provision of an anode and cathode, (2) the maintenance of an electrical circuit, (3) the presence of moisture, and (4) the presence of oxygen (Mindness and Young, 1981). Under most conditions, good quality concrete provides adequate protection of embedded steel against corrosion. This is due to the high alkalinity of the concrete (pH of about 12 to 12.5) which causes a passive oxide film that prevents corrosion to form on the surface of the steel. The degree to which concrete will provide satisfactory protection is in most instances a function of the quality of the concrete, the depth of concrete cover, and the degree to which good practices are followed throughout the entire construction operation (ACI, 1979).

The quality characteristic of concrete includes low permeability and proper mixture proportions. The permeability of concrete is a major factor affecting the process of corrosion of embedded materials. Low water-cement ratio with well-graded coarse and fine aggregates produce less permeable concrete and thus provide greater assurance against corrosion. Water-cement ratios should not exceed 0.40 for concrete exposed to sea or brackish water, or in contact with more than moderate concentrations of chlorides at the water or ground line. If the water-cement ratio is raised to 0.45, the concrete cover over the steel should be increased 1/2 in. Studies of durability of concrete (seawater exposure) showed that cements containing 5 to 8 percent tricalcium aluminate (C_3A) showed less cracking due to steel corrosion than cements with a C_3A content less than 5 percent (Verbeck, 1968).

Permeability is reduced by increased hydration of the cement. Concrete should be cured properly until at least 90 percent of the design strength has developed.

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Table 2

Partial List of Deleterious Aggregates

Andesites and tuffs
Chalcedonic cherts
Dacites and tuffs
Fractured, strained, and
  inclusion-filled quartz
  and quartzites
Opaline cherts
Opaline concretions
Phyllites
Quartzose cherts
Rhyolites and tuffs
Siliceous dolomites
Siliceous limestones
Siliceous shales

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Concrete cover over reinforcing steel should be adequate. In a well-cured concrete with low water-cement ratio, the depth of carbonation (calcium hydroxide is converted to calcium carbonate by atmospheric carbonation which destroys protective oxide film on the surface of the steel) is unlikely to exceed 25 mm, and therefore, a concrete cover of 25 to 40 mm over reinforcing bars should be adequate in most instances (Mindness and Young, 1981). Where more severe conditions of exposures are encountered or concrete with fairly high permeability is used, the cover should be increased at least 50 mm (Mindness and Young, 1981). Protection against penetration of salts to reinforcing steel in seawater exposure is 3 in., while the American Association of State Highway and Transportation Officials (AASHTO) recommends 4 in. except for precast piles.

In addition, other practices have to be followed to minimize corrosion. These are good concreting practices (workmanship), good drainage, and good specifications and inspection.

Good workmanship is a most important factor in securing uniform concrete of low permeability. Tnis includes good consolidation and finishing practices, and precaution against segregation.

In areas of severe exposures, particular attention should be given to design details dealing with drainage to insure that the water will drain.

The passive oxide film on steel can be destroyed by chloride ions. Chlorides may enter the concrete from three major sources: (1) admixtures ($CaCl_2$), (2) deicing salts, and (3) seawater. ACI Committee 201 (ACI, 1977) suggests the following limits for chloride ion (Cl^-) in concrete prior to service exposure, expressed as a percent by weight of cement.

1.	Prestressed concrete	0.06 percent
2.	Conventionally reinforced concrete in a moist environment and exposed to chloride	0.10 percent
3.	Conventionally reinforced concrete in a moist environment but not exposed to chloride	0.15 percent
4.	Above ground building construction where the concrete will stay dry (does not include locations where the concrete will be occasionally wetted--such as kitchens, parking garages, and waterfront structures)	No limit for corrosion

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These limits should be applied with good judgement because other factors such as moisture and oxygen are necessary for electrochemical corrosion.

3. Recommendations for Minimizing Adverse Effects on Long Term Durability of Concrete

The following practices and precautions are recommended to provide durable concrete for aboveground engineered disposal facilities using portland cement concrete as the primary construction material.

3.1 Frost Action

The following items compose the recommendations to overcome frost damage.

3.1.1 Design the structure to minimize exposure to moisture. The building geometry must provide good drainage, with no surface that will provide for potential ponding. Therefore, use a sloped roof rather than a flat roof. Floor slabs must have a vapor barrier between the slabs and grade. Unnecessary joints must be eliminated.

3.1.2 Use low water-cement ratio. For structures of this type the water-cement ratio should not exceed 0.50.

3.1.3 Provide air entrainment in the mixture. It is recommended that air-entrained concrete be used for this construction and Table 3 shows the recommended air contents derived from ASTM (1977).

3.1.4 Use only suitable materials.

3.1.4.1 Cement. The several types of portland and blended cements, in properly proportioned and produced air-entrained concrete, will provide for resistance to cyclic freezing. However, to resist severe sulfate attack, Type V is required. Therefore, for this added protection, Type V conforming to ASTM C 150 is recommended.

3.1.4.2 Aggregate. The aggregates used for this construction should be the very best available, as long as it is cost-effective to obtain them. Careful judgement must be used in deciding the cost-effectiveness factors considering the nature of the material to be disposed. The aggregates should be thoroughly characterized by the physical tests required, i.e., petrographic examination, absorption, specific gravity, soundness tests, and determination of pore structure. These tests are described in the Handbook for Concrete and Cement (US Army Engineer Waterways Experiment Station, 1949).

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Table 3

Recommended Air Contents for Freeze-Thaw Resistance

Nominal Maximum Aggregate Size		Air Content, Percent	
mm	(in.)	Moderate Exposure	Severe Exposure
9.5	(3/8)	6	7.5
12.5	(1/2)	5.5	7
19.0	(3/4)	5	6
37.5	(1-1/2)	4.5	5.5
75	(3)	3.5	4.5
150	(6)	3	4

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3.1.4.3 Admixtures. Air-entraining admixtures should conform to ASTM C 260.

3.1.5 Use proper curing. Proper curing procedures and materials are required for durable concrete; they should comply with ACI Standard 308-81 (ACI, 1981). Depending on the structural member being cured, the techniques of inundation, water spray, wet burlap, plastic membrane, and sprayed-on membrane are recommended. The curing period should be that established in the laboratory which achieves a specified strength with that particular curing technique.

3.1.6 Use sound construction practices. Good construction practices should be implemented to obtain durable concrete. These include proper mixing, placing, handling, and consolidating of the concrete; protection against extreme temperatures; good forming techniques; use of a form material that will give a smooth dense finished surface; proper curing, especially after form removal; and immediate repair of any surface defects.

3.2 Aggressive Chemical Exposure

Protection against sulfates in the soil or groundwater is achieved by the use of sulfate-resistant cement in dense, high quality concrete with a low water-cement ratio. Table 4 provides certain recommendations for sulfate protection taken from ASTM (1977).

Protection against mild acid attack is achieved by the use of a dense concrete with a low water-cement ratio. However, surface coatings or treatments are required to protect against groundwater, soil, or accidental spills containing high concentrations of acids. ACI Committee 515 (ACI, 1974) has recommended certain barrier coatings for concrete under certain conditions. Table 5 gives recommendations for dampproofing coatings and Table 6 gives recommendations for protective barrier systems. Tables 5 and 6 were taken from ACI (1974).

3.3 Abrasion

Abrasion resistant concrete surfaces will be achieved by implementation of the following measures.

3.3.1 Use low water-cement ratio.

3.3.2 Use well-graded, hard, tough fine and coarse aggregates, with a maximum size of 1 in., meeting the requirements of ASTM C 33 (ASTM, 1981).

3.3.3 Use the lowest slump concrete that is practical for the working conditions (maximum 3 in., 1 in. for toppings).

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3.3.4 Air content should be consistent with exposure conditions.

3.3.5 Use a topping layer over the main slab if severe wearing conditions are anticipated.

3.3.6 Finish (float and trowel) the surface only after the surface has lost its sheen.

3.3.7 Vacuum dewatering techniques can be used to remove excess water immediately after placing, resulting in a more dense concrete with increased strength and surface enhancement against wear.

3.3.8 Curing techniques of water spray, damp burlap, or cotton mats are recommended and the curing should be for 7 days.

3.4 Reactive Aggregates

3.4.1 Avoid alkali-reactive aggregates. If possible, reactive aggregates should not be used. However, if their use is unavoidable, they should only be used with low-alkali cement (maximum 0.60 percent equivalent Na_2O).

3.4.2 Determine alkali-carbonate reactivity and use measures to reduce the effects of this reaction.

3.4.2.1 Avoid reactive rocks.

3.4.2.2 Dilute the reactive rocks by the inclusion of nonreactive rocks.

3.4.2.3 Use low alkali cement.

3.5 Corrosion of Embedded Materials

The following measures should be employed to protect embedded items from corrosion:

3.5.1 Use low water-cement ratio.

3.5.2 Avoid honeycombing (provide good consolidation).

3.5.3 Use adequate concrete cover.

3.5.4 Design against structural cracks.

3.5.5 Keep chloride content below permissible values.

3.5.6 Provide protective coating on the concrete.

3.5.7 Provide coating on the steel.

3.5.8 Use good curing techniques.

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Table 4

Protection of Concrete Subject to Sulfate Attack

Exposure	Sulfate in Water, ppm	Type Cement Required	Recommended Water-Cement Ratio, max.
Severe to very severe	1,500 to 10,000 and greater	Type V	0.45
Mild to moderate	150 to 1,500	Type II IP(MS) IS(MS)	0.50

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Table 5

Recommended Dampproofing Materials and Techniques

Recommended Material or Technique	Siting Condition: Above Grade, Ext. Face	Above Grade, Int. Face	Covered or Buried, Ext. Face	Covered or Buried, Int. Face
Portland cement Paint (water based)	X	X	/	X
Asphalt (cold applied)	X	X	X	//
Latex Paint (PVC)	X	X	/	X
Epoxy Paint (two-component)	X	X	/	X
Chlorinated Rubber Paint(solvent based)	X	X	/	X
Polyurethane Paint (moisture-cured or two-component)	X	X	/	X

/Exterior coating also required (see list in this table for other recommended materials).

//Interior coating also recommended (see list in this table for other recommended materials).

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Table 6

Protective Barrier Systems in Chemical Environment

Exposure	Protection Against Barrier System	Expected Attack
Severe	Composite system of: (1) Asphalt membrane covered with acid-proof brick and chemical-resistant mortar (greater than 6 mm thick)	Concentrated acid or acid/solvent material
	(2) Epoxy system (sand filled) topped with unfilled pigmented epoxy (0.5 mm to 6.75 mm thick)	Water, dilute acids, strong alkalies, and salt solutions
Severe	Neoprene sheet (precured, PVC sheet (plasticized), glass-reinforced (GR) epoxy, GR polyester (0.5 mm to 6 mm thick)	Organic acids (ph$<$3), salt solutions, strong alkalies
Moderate	Bituminous materials, sand-filled systems of epoxy, polyester or polyurethane (3 mm to 9 mm thick)	Abrasion and dilute acids (intermittent exposure)
Mild	Asphalt, chlorinated rubber, epoxy, vinyl, polyurethane, neoprene, coal tar, coal tar epoxy, coal tar urethane, styrene-acrylic copolymer, acrylic, polyvinyl butyral	Salts (such as deicing), frost damage, solutions with ph$>$4

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3.6 Covered Versus Aboveground Structure

The recommendations presented so far have been applicable to aboveground structures. However, if a structure is covered, the information in Tables 5 and 6 must be put to use. The details of the materials and practices will be dictated by the characterization of the cover material. All other recommendations, as shown for the aboveground case, are applicable for underground structures.

3.7 Testing of Component Materials and Final Mixture

Once a decision has been made to construct an engineered disposal facility at a particular location, a test program should be designed and specified that will result in the use of the very best materials to produce the most durable concrete possible. The program should be designed so that the carefully selected components are fully characterized after having been thoroughly tested. The concrete composed of these components should also be fully characterized as to its response to the particular environment.

This program should be followed, once construction begins, with a carefully planned program of quality control and quality assurance. This will insure that the proper components will be used to produce a quality product capable of the high level of durability required.

4. Summary and Conclusions

Adherence to the guidelines and recommendations contained and referenced herein, along with good practices of production and construction, will produce a durable concrete capable of long life. The service life will be further enhanced if proper and timely repair and maintenance procedures are employed, should their need arise. There is no mathematical model that can predict service life of a structure, but by producing the best concrete possible and employing the best construction practices, the implication is that the material and structure will function for many years.

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13. ABSTRACT (200 words or less)

The study reported herein contains the results of Task 2b (Technical Requirements for Aboveground Vault Disposal of Low-Level Radioactive Waste) of a four-task study entitled "Criteria for Evaluating Engineered Facilities." The overall objective of this study is to ensure that the criteria needed to evaluate five alternative low-level radioactive waste (LLW) disposal methods are available potential license applicants. The aboveground vault disposal alternative is one of several methods that may be proposed for disposal of low-level radioactive waste. In this report, the term aboveground vault refers to an engineered structure with roof, walls and floor enclosing the disposal space. The limited experience and knowledge gained with this method are described and updated in this report. The short term experience does not conclusively demonstrate the capability of this method to satisfy the Part 61 Performance Objectives. A generic description of the features and components and operation of an aboveground vault disposal facility is provided. Features and components that could enhance the long-term performance are described. The applicability of existing criteria developed for near-surface disposal (10 CFR Part 61 Subpart D) to the aboveground vault disposal method, as assessed in Task 1, are reassessed herein. With few exceptions, these criteria were found to be applicable in the reassessment. These conclusions differ slightly from the Task 1 findings.

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